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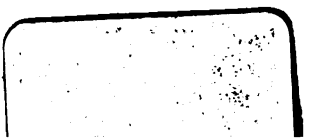
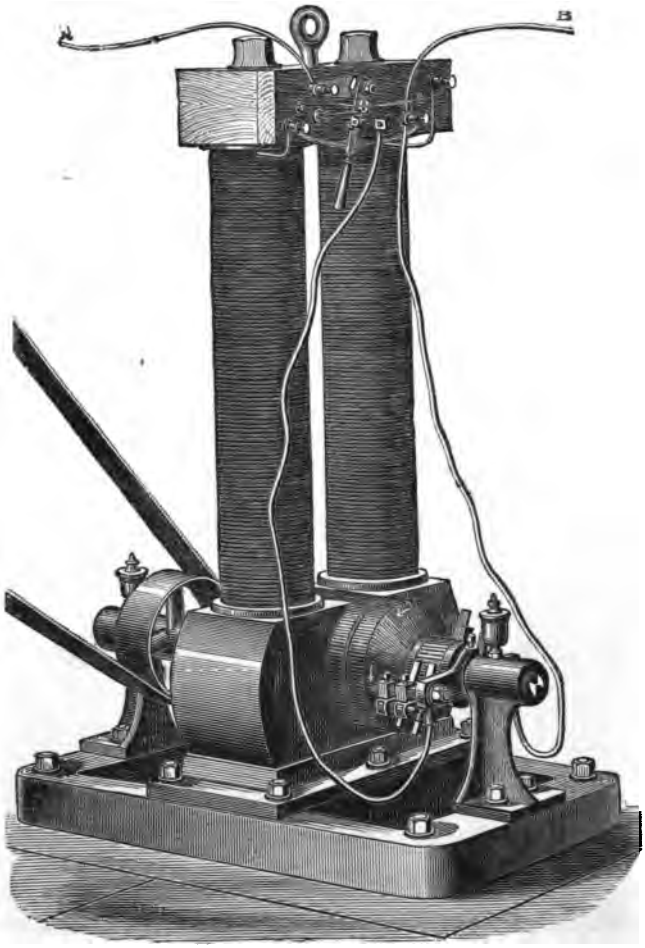


PRACTICAL ELECTRIC LIGHTING.



EDISON'S SHUNT-WOUND DYNAMO.

(*For description, see page 62.*)

PRACTICAL

ELECTRIC LIGHTING.

BY

A. BROMLEY HOLMES.

ASSOC. M. INST. C.E.

WITH SIXTY-TWO ILLUSTRATIONS.

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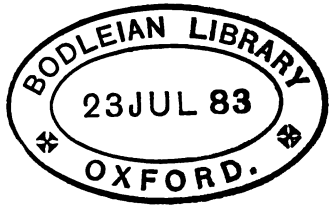

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PREFACE.

PUBLIC attention has, during the past twelve months, been directed to the Electric Light as a possible means of general illumination. On the one hand, enthusiastic believers in electricity have predicted its rapid adoption in the place of gas, and on the other, equally extreme views have been put forward denying the possibility of any extensive introduction of the new system of lighting, chiefly on account of its alleged greater cost.

At the present time a feeling is steadily gaining ground that the cheapest light need not of necessity prove the most economical, and that health, cleanliness, and comfort deserve consideration when the rival methods of lighting are discussed.

Many who take an interest in the Electric Light find it difficult to judge between the conflicting statements put forward, and are unable to arrive at a satisfactory conclusion as to its merits.

The aim of the following pages is to explain in simple language the principles involved in the production of the

light, and to afford information as to the construction and working of the apparatus employed for this purpose without preference for any particular machine, lamp, or system.

The object has not been to produce a scientific treatise, or to give minute detailed descriptions, for which the reader is referred to the numerous larger works and papers on the subject, especially those of Maxwell, Deschanel, Thompson, Lodge, and Dredge, to which the author is indebted for many particulars.

It is hoped those who are interested in the practical working of the Electric Light may find in the following pages some information which may prove of use, and to a certain extent repay the perusal.

1, Crosshall Street, Liverpool,
May, 1883.

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PRACTICAL ELECTRIC LIGHTING.

CHAPTER I.

Introduction.

In the year 1810, Sir Humphry Davy exhibited at the Royal Institution in London, an electric light, produced by means of two small pieces of carbon and a powerful galvanic battery. This experiment attracted a considerable amount of scientific attention.

A few years later, Michael Faraday commenced the series of experimental researches which may be said to have formed the foundation of modern electrical science; a field in which he was ably followed at a more recent period by the careful investigations of James Clerk Maxwell.

Shortly after Faraday's experiments were made public, the first magneto-electric machines were constructed, by means of which, mechanical energy could be transmuted into energy in the form of an electric current.

Improvements in design and construction were from time to time made in these machines, by which their efficiency was increased, but it is only within the last few years that the possibility of employing the electric light for purposes of general illumination has been seriously considered.

Although the light has been exhibited throughout this country on a scale sufficiently large to call attention to its many advantages, much still remains to be done before electricity can be laid on from house to house in the same way as gas, and at an equal cost.

The use of gas is attended with many inconveniences which render it unsatisfactory for interior illumination, especially for dwelling houses; but the introduction of the electric light does not necessarily entail the gradual disuse of gas and the loss of the capital now employed in its manufacture. In addition to the numerous cases in which gas is a simple and satisfactory illuminant, its use as a source of heat and power is capable of enormous extension. For these purposes it can be supplied of a cheaper quality than is practicable when used for lighting, and with corresponding advantage both to the producer and consumer.

In the introduction of a new invention, however meritorious, there is always a considerable amount of prejudice to overcome, arising frequently from imperfect knowledge and opposing interests, assisted by the fact that all new inventions must be hampered by imperfections and difficulties, which only time and experience can overcome.

When, early in the present century, gas lighting was first introduced, Sir Walter Scott wrote from London that there was "a *madman* proposing to light the town with—what do you think?—why with smoke." It was generally assumed that the pipes conveying gas would be hot and liable to cause conflagrations, and people used to approach

them cautiously, under the belief that a careless touch might cause a burn.

Experience has shown that, although the use of gas is attended with a certain amount of risk arising from imperfect fittings or careless treatment, the number of accidents which occur annually are practically insignificant.

The introduction of the electric light has been delayed quite as much by exaggerated statements of its advantages, which could only lead to certain disappointment, as by the opposition incident to the introduction of any novelty.

At present, under many circumstances, gas has material advantages over electricity, and much progress has to be made before a general system of electric supply can be effected on a reasonable commercial basis.

Until the light can be supplied from central generating stations, it is probable that private installations for manufacturing establishments, public buildings, shops and dwelling houses will continue rapidly to increase in number—especially as electricity can be produced in small quantity at a cost not very much greater proportionally than for larger quantities, being, in this respect, unlike gas, which must be manufactured on a very large scale to be economical.

The production of the electric light is much less complicated than the manufacture of gas, and when the necessary precautions are observed, quite devoid of danger. It is desirable, however, that the principles on which the requisite apparatus is designed should be correctly understood, and that a sufficient knowledge should be acquired

of the details of construction of the machinery, and of the practical rules that require to be observed in its management.

Information on the above points will be found in the following chapters.

It is impossible in dealing with a subject of this kind to avoid technicalities, and therefore the ordinary terms used by Electricians are employed; each technical expression when it first occurs being explained in as simple a manner as possible.

CHAPTER II.

Frictional Electricity. Potential. Electromotive Force. Units of Measurement.

Up to the present time no theory has been put forward which explains in a satisfactory manner what electricity really is. In many respects it resembles light and heat, and like them serves as a medium for the transmission of energy. For the present purpose, it may be regarded as a very subtle fluid, pervading everything to a greater or less degree; it must be understood, however, that it is considered as a fluid only for convenience of explanation.

Electricity cannot be created out of nothing, nor can it be destroyed; but it is possible by the various apparatus described hereafter to alter the distribution of electricity, that is to say, to collect it at different places in any required quantity, and to transfer it from one point to another as may be desired. Although very little is known as to the real nature of electricity, a comparatively accurate knowledge has been attained of the ways in which it can be collected, regulated, and applied to useful purposes.

Positive and negative Electricity are two conventional terms used to express different degrees of electrification. A glass rod, if rubbed with a silk handkerchief, acquires an attractive power for light

objects, and is said to be charged with *positive* electricity. A stick of sealing wax rubbed with flannel is found to possess powers of attraction, but of a different character, and is stated to be *negatively* electrified.

The kind of electricity generated depends, not only on the *material rubbed*, but also on the *rubber*. For example, *negative* electricity can be produced on the *glass rod* by rubbing it with a *catskin* instead of a silk handkerchief.

Attraction and Repulsion.—Bodies charged with electricity of the *same kind* repel one another, and bodies charged with electricity of *different kinds* attract each other. This can easily be demonstrated by suspending two little pith balls by hairs or silk from a bent wire support (see Fig. 1), and charging them by contact with a stick of sealing wax, or a glass rod, excited as described above. They will be found to repel each other if *both* are charged with either positive or negative electricity, and to attract each other when one is charged with positive and the other with negative electricity.

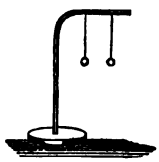


Fig 1.

The pith balls will exercise the above attractive or repulsive power, even if a sheet of glass or other non-conductor is introduced between them.

Potential is the word employed to express various degrees of electrification. Bodies positively electrified may be conveniently considered as of *high potential*, and those *negatively* electrified as of *low potential*. The earth's surface is usually stated to be of *zero potential*, and forms a reference point from which to measure relative

degrees of electrification of bodies, which may be of higher or lower potential than that of the earth's surface.

When electricity is regarded as a fluid, its supposed flow or passage is called *a current*, and any substance through which it flows *a conductor*. Bodies offering such great resistance as practically to prevent the passage of electricity are named *insulators*. The path through which a current passes is termed *a circuit*, which when continuous is called *a closed circuit*, but when there is a break in it *an open circuit*.

When two dissimilar metals touch each other there is a difference of potential at the point of contact. For example, if zinc is in contact with copper, it is of higher potential than the copper. If a series of discs of copper, zinc, and wet cloth are arranged one over the other in the above order, the wet cloth will form a conductor between each pair of metal discs, and a current of electricity will flow when the circuit is completed by joining the lowest copper disc by a wire to the uppermost zinc disc. Such an arrangement is called a **Voltaic Pile** (after its inventor *Volta*), and the difference of potential produced is proportional to the number of the pairs of discs.

A difference of potential between two points connected by a conductor produces a passage of electricity from one to the other till the potential of both points is the same, when there can be no further transference between them.

When a current is passing it is evidence that the potential of each point in the circuit is less than that of each preceding point.

The flow of electricity resembles in many respects the flow of water, and difference of potential difference of level or pressure.

If, for example (see Fig. 2), A represents a vessel containing water, which can be emptied through the pipe B by the tap C, and D D D are three vertical branches of the pipe B, then so long as the tap is closed the level of the water will be found to be the same throughout, for instance at the line E E. That is to say, there will be no flow and no difference of level. But if the tap C is opened (see Fig. 3), it will be found that the level in each of the pipes D will be lower than that in the vessel A, in proportion as it is nearer to the tap, and the height of the water in each pipe will indicate the relative pressure at that particular point of the tube B.

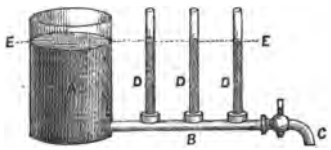


Fig. 2.

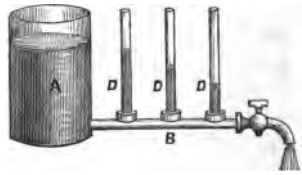


Fig. 3.

In the same way, if a conductor through which an electric current is passing is examined, the potential will be found to vary just as the water level does in the above example.

Electromotive force (sometimes written briefly **E. M. F.**) is the name used to express the force which tends to move electricity from one place to another, and

is produced by, and proportional to, the difference of potential of the two points. When two points of different potential are connected by a conducting medium, the electromotive force will produce a current, but until the points are so joined it is unable to act.

Resistance is offered by all substances to the passage of the electric current, and varies in amount with the nature of the substance. Most metals offer but small resistance, and are called good conductors. Wood and stone offer considerably greater resistance, whilst silk, glass, and ebonite are practically non-conductors, preventing almost entirely the passage of the current.

Electricity being invisible and imponderable, it is impossible to apply to it the ordinary standards of measure, but Electricians have devised special units of measurement, which are of two kinds, called **absolute units** and **practical units**, the ratio between the two being always some power of the number 10.

It has been decided that in these measurements *length*, *mass*, and *time*, shall be expressed respectively in *centimetres*, *grammes*, and *seconds*. This is called the **centimetre-gramme-second method**, or, more briefly, **C. G. S. measure** (a gramme is equal to 15·432 grains, and a centimetre to 0·3937 of an inch). The *weight* of a body must not be confused with its *mass*. The mass is simply the amount of matter contained in the body, while what is called its weight is equivalent to the mass multiplied by the accelerating effect of gravity, or the earth's attraction, which varies at different parts of the surface, but may be averaged at 32·2 feet (or 981 centimetres) per second.

The absolute units of the above system are for the most part too large or too small for practical use, as they would involve figures of inconvenient length, but two examples may be given, viz.:

The Dyne, or *absolute* unit of *force*, is that force which, acting for one second on a mass of one gramme, imparts to it a velocity of one centimetre per second. The *weight* of one gramme is equal to a force of $1 \times 981 = 981$ dynes.

The Erg, or *absolute* unit of *work*, is the work requisite to move a body one centimetre against a force of one dyne. As the weight of one gramme is equal to 981 dynes, the work of raising one gramme one centimetre against the force of gravity is 981 ergs. An erg is about equal to $\frac{1}{13,560,000}$ of a foot-pound. (A **foot-pound** representing the work done in raising one pound weight one foot high).

The Watt, or *practical* unit of *work* (or rather of the *rate of doing work*), is equal to 10 million ergs (10^7 absolute C. G. S. units) *per second*, or to the work produced in that time by one ampere of current of an E. M. F. of one volt.

The practical units of most frequent occurrence are the volt, the ohm, and the ampere.

The Volt (equal to 10^8 absolute units), or measure of *electromotive force*, or of *difference of potential*, is equal approximately to the electromotive force possessed by one Daniell cell (described in the next chapter); accurately it is 0·95 of a cell.

The Ohm (equal to 10^9 absolute units), or measure of *resistance* (sometimes called the British Association or B. A. unit), is approximately equal to the resistance of

129 yards of copper wire $\frac{1}{16}$ of an inch in diameter, or to 105 centimetres of mercury, one square millimetre in section. The *Siemens unit* of resistance is that of a column of mercury one square millimetre in section, and one metre long, and is equal to ·955 of an ohm.

The Ampere, formerly called *the Weber* (equal to 10^1 absolute units) is the measure of *strength of current*.

ERRATA.

Page 19 *should read*—

The Ampere equal to 10^{-1} absolute units.
The Coulomb „ „ 10^{-1} „ „

Page 20 *should read*—

The Farad „ „ 10^{9} „ „

$I = \frac{E}{R}$ where I stands for *intensity* or strength of current.

The word *intensity*, however, has been used in various senses in electrical matters, and is apt to lead to confusion.

The Coulomb (10^1 absolute units) is the unit of *quantity*, and represents the amount of electricity given by one ampere of current acting for one second of time.

In any given circuit the *strength of current* expressed in *amperes* is equal to the *quantity* of electricity expressed in

coulombs, which flows past any point in the circuit in *one second.*

This is represented by the formula,

$C = \frac{Q}{t}$ or $Q = Ct$ where

C is current in *amperes*,

Q is quantity of electricity in *coulombs*,

t is time in *seconds.*

For example, if a current of a strength of 5 amperes flows for the space of 10 seconds, the amount of electricity which passes during that period will be 50 coulombs.

The Farad (10^9 absolute units) is the measure of *capacity*, and is such that a condenser of *one farad* capacity would be raised to the potential of *one volt* by a charge of *one coulomb* of electricity, or, in other words, by a current of a strength of *one ampere* acting for *one second.*

A condenser of the capacity of one farad would be inconveniently large; and therefore, **the microfarad**, or one millionth part of a farad, is the unit generally used.

Since it is frequently necessary to measure quantities millions of times greater or less than the practical units, the prefix **mega** has been adopted to represent *one million times*, **micro** *one millionth part*, and **milli** *one thousandth part.* In this way a **megohm** signifies one million ohms, and **milliampere** one thousandth part of an ampere.

The Joule, or unit of *heat*, is the amount required to raise *one gramme* mass of water *one degree centigrade*, and is equal to the work of 42 million ergs, or $3\frac{1}{10}$ foot pounds.

The work required to raise *one pound* weight of water *one degree Fahrenheit* is equivalent to 772 foot pounds.

The heat developed in a circuit depends on the strength of current, the time for which it acts, and the resistance of the conductor, and may be calculated by the following formula, called **Joule's law**:—

$$H = \frac{C^2Rt}{4 \cdot 2}$$

C is current in *amperes*.

R is resistance in *ohms*.

t is time in *seconds*.

H is heat in *joules* (or gramme-degrees) as above.

The practical electrical units have been called after the eminent Scientific Investigators whose names they bear. The units of E. M. F. and of capacity being abbreviations of Volta and Faraday, the other names being retained in full.

The horse power is the unit of *rate of work* commonly used by engineers. *Nominal horse power* has no definite meaning, and is, for the most part, a misleading expression.

An **Indicated**, or **actual horse power** is equivalent to 33,000 lbs. raised one foot high in one minute, or 550 foot-pounds per second. The work expended in a circuit in producing a current of a certain strength, and of known electromotive force, or against a known resistance, can be calculated by the following formula, which, however, only represents the work expended in the current itself, and does not make allowance for that wasted in the generator and in the prime motor,

$W = C E$ or $W = C^2 R$.

Or $H P = \frac{C E}{746}$ or $= \frac{C^2 R}{746}$, where

C is current in *amperes*,

E is electromotive force in *volts*,

R is resistance in *ohms*,

W is work in *watts*,

H P is actual *horse power*.

The English horse power, as stated above, is equal to 746 Watts, and the French **cheval de vapeur** to 785 Watts.

CHAPTER III.

Thermopile. Galvanic Batteries. Arrangement of Cells.

It has been explained in the previous chapter how electricity can be produced by rubbing a glass rod or a stick of sealing wax with a suitable rubber.

Frictional electricity can be generated in greater quantity by the use of machines formed with a rotary glass cylinder or plate (or an ebonite disc), against which are pressed rubbing pads to cause the necessary friction.

Electricity obtained in the above manner can, with suitable apparatus, be used to demonstrate numerous electrical phenonema, but when a supply capable of affording a continuous illumination is required, it is necessary to seek other methods of production. The powerful dynamo-electric machines generally used for this purpose will be described in a subsequent chapter.

The action of the **Voltaic Pile** has already been explained. The **Thermopile** is an apparatus in which a current is generated by heating the joints of a chain composed of two metals arranged alternately. The best effects are produced when antimony and bismuth, or German silver and ordinary tinned iron, are selected for the purpose.

The Galvanic Battery is the simplest arrangement by which **electricity in the form of a current** can be produced for experimental purposes on a small scale; its cost, however, precludes its use for electric lighting, except for very short displays. If two plates, one of zinc and the other of copper, are immersed in a vessel containing an exciting fluid, consisting of water acidulated with sulphuric acid, and if a copper wire is attached to the top of each plate (see Fig. 4), then so long as the wires are not connected to each other no action will take place, but if the wires are joined it will be found that a circulation of electricity commences, the current passing through the wire from the copper plate to the zinc plate, and completing the circuit through the liquid from the zinc to the copper (see Fig. 5). The chemical action being that the zinc becomes oxidised by the action of the acid and hydrogen is set free and gradually collects in bubbles on the copper plate. An arrangement of two metal plates in a containing vessel as above described is called a *cell*. A *galvanic battery* may consist of any number of cells connected together.

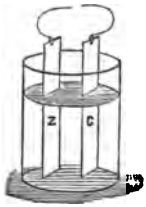


Fig. 4.

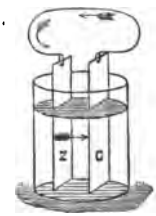


Fig. 5.

The portion of the copper plate *from which* the current flows through the wire is called the *positive pole* of a battery, and the corresponding point on the zinc plate *to which* the current flows is called the *negative pole*.

The plates which compose a battery are termed *elements*,

the zinc being called the positive, and the copper the negative element. Care must be taken not to confuse the expressions positive or negative *pole*, and positive or negative *element*. It will be noticed that the zinc plate is the *positive element*, and yet its upper extremity is called the *negative pole*, and similarly that the copper plate forms the *negative element* and *positive pole*. It will also be noticed that the word *positive* always applies to the element or pole *from which* the current flows, and the word *negative* to the element or pole *to which* the current flows. The distinction between these terms will be more readily understood if the word *element* is taken to apply to the lower portion of the battery plate which is immersed in the exciting fluid, and the word *pole* to the upper portion of the plate which is outside the fluid, and to which the conducting wire is fixed. The positive pole of a battery is sometimes termed the *anode*, and the negative pole the *cathode*. Conducting wires attached to the two plates are called *electrodes*.

The bubbles of hydrogen gas liberated at the negative element resist the passage of the current, and being readily oxidisable, set up an *opposing* electromotive force. A battery in this condition is said to be "**polarised**."

The electromotive force of a cell is equivalent to the difference of potential between its electrodes when unconnected, and is independent of the size of the elements, and determined solely by the materials of which they are constructed.

For example, the natural difference of potential between zinc and carbon being greater than that between zinc

and copper, a cell of greater E. M. F. can be made with elements composed of the former materials than if constructed with the latter.

When the cells of a battery are coupled up **in series**, that is to say, when the copper plate of the first cell is connected to the zinc of the second cell, and the copper of the second to the zinc of the third, and so on, the copper plate of the last cell being coupled to the zinc of the first (see Fig. 6), the E. M. F. of the battery is proportional to the number of cells. For example, if a battery consists of three cells coupled up as above, the E. M. F. will be three times that of a single cell.

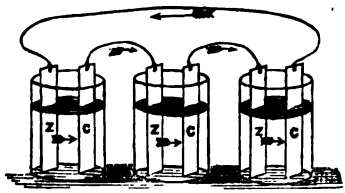


Fig. 6.

Before the wires attached to the extreme poles of the series of cells are connected, the difference of potential between them is equal to three times that of a single cell. When, however, the wires are joined, and the current flows, this difference is lessened.

The fall of potential in any portion of the circuit is proportional to the resistance of that part. In the above example (Fig. 6), if the **external resistance** of the connecting wire is twice that of the **internal resistance** offered by the battery plates themselves, and that portion of the exciting fluid which separates them, the fall of potential in the wire will be double that in the cells.

That is to say, if the E. M. F. or difference of potential of each cell is denoted by 3, and consequently that of the series of cells by 9, the fall of potential in the wire when the poles are connected will be 6, and in the battery 3 (or in each cell 1). The total electromotive force (represented by 9) will be expended, six parts in driving the current through the wire, and three parts in forcing it through the cells. Before the circuit is completed the potential at each point (the wire being attached only to zinc of first cell) will be as follows :—In the wire 0 ; first cell, 3 ; second cell, 6 ; third cell, 9 ; but when the circuit is completed (by connecting the wire to copper of third cell), in the wire 6 to 0, first cell, 3 to 2 ; second cell, 5 to 4 ; third cell, 7 to 6.

The strength of current given by a battery varies with the **resistance** as well as with the **electromotive force**, and therefore can be increased, not only by adding more cells in series, but also by lessening the internal resistance of the cells. This can be done by increasing the size of the battery plates, or, more simply, by coupling all the positive poles of the battery together, and all the negative poles together. (See Fig. 7.)

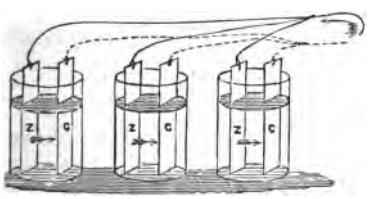


Fig. 7.

The E. M. F. of these cells coupled in this way is only equal to that of a single cell, but the current will be greater, because the internal resistance will be only one-third of that of a single cell.

This method is called *coupling up* **parallel**, or **for quantity** (as it used to be termed), to distinguish it from the plan of coupling up **in series**, or **for intensity.**

The amount of useful effect that can be produced by any battery depends on the external and internal resistances being correctly proportioned one to the other, the maximum result being attained when the internal resistance of the battery is equal to that of the external circuit.

For example, if with a battery of eight cells, each cell has an E. M. F. of two volts and a resistance of eight ohms, and the external circuit a resistance of sixteen ohms, the best effect will be produced if the cells are arranged four in series and two abreast. (See Fig. 8.)

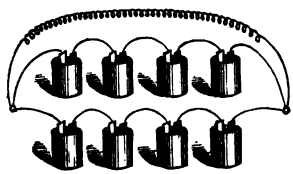


Fig. 8.

For by Ohm's law $C = \frac{E}{R}$ where

C is current in *amperes*,

E is electromotive force is *volts*,

R is resistance in *ohms*.

In the above case, where the cells are arranged in two rows of four in series,

$E = 4 \times 2 = 8$ volts and $R = \frac{4 \times 8}{2} = 16$ ohms (internal resistance) + 16 ohms (external do.) = 32 ohms.

Therefore $C = \frac{E}{R} = \frac{8}{32} = \frac{1}{4}$ ampere.

If the cells are arranged eight in **series**,

$E = 16$ volts, and $R = 64 + 16 = 80$ ohms,

and $C = \frac{E}{R} = \frac{16}{80} = \frac{1}{5}$ ampere.

Or, if the cells are all arranged **parallel**, $E = 2$ volts,

and $R = 1 + 16 = 17$ ohms,

and $C = \frac{E}{R} = \frac{2}{17}$ ampere.

It is, therefore, evident that for an external resistance of sixteen ohms, the above eight cells will produce the strongest current when arranged four in series and two parallel, as in Fig. 8, or, generally, that to give the best result the internal resistance of a battery should equal that of the external circuit.

It should also be noted that it is not well to couple more cells in series than are necessary to make the internal equal to the external resistance, because, however many cells are coupled in series, the strength of current can never exceed that given by a single cell. This can readily be seen if the external circuit be formed of a short thick wire, the resistance of which is so small that it may be neglected. Then for a single cell of an E. M. F. of two volts, and resistance of eight ohms,

$C = \frac{E}{R} = \frac{2}{8} = \frac{1}{4}$ ampere, or if ten cells be arranged in series,

$C = \frac{E}{R} = \frac{10 \times 2}{10 \times 8} = \frac{20}{80} = \frac{1}{4}$ ampere as before, and so on for any other number of cells.

In cases where, as above, the resistance of the external circuit is small, the cells of a battery should be joined up

parallel, and the strength of current will be found to increase proportionately to the number of cells employed.

There are many different kinds of batteries, of which the following are more generally used, and may be described as types; of these the Daniell has an electromotive force of about one volt, and the Leclanché about 1½ volts; the E.M.F. of the other batteries varies from 1¾ to 2 volts. A battery should be selected with regard to the purpose for which it is required.

For such instruments as electric bells or telephones, the **Leclanché Battery** is the most suitable. The positive element of this battery is zinc, and the negative a mixture of carbon and peroxide of manganese, contained in an inner porous cell; the exciting fluid is a solution of chloride of ammonium or common sal-ammoniac. These batteries, however, do not maintain a current of constant strength, which is essential for the production of electric light, the most suitable for that purpose are the Grove or the Bunsen.

Grove's Battery (see Fig. 9) consists of an inner cell of porous earthenware, containing a platinum plate, which forms the negative element, and its exciting solution of nitric and sulphuric acids in the proportion of three parts of the former to one of the latter.

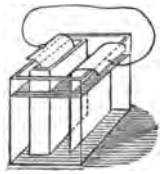


Fig. 9.

The outer cell is made large enough to contain the inner cell and a plate of zinc, which is the positive element, and requires an exciting fluid of sulphuric acid mixed with seven times its bulk of water. The zinc plate is frequently

made in the shape of the letter U, and passes up on each side of the inner cell containing the platinum plate.

Bunsen's Battery has an inner porous cell and an outside containing jar, similar to the one used for Grove's battery, and the exciting fluids and general arrangements are the same in both batteries. The positive element is a zinc plate, but the negative element is formed of carbon, generally obtained from the deposited carbon found in gas retorts.

The Maynooth Battery, with elements of cast-iron and zinc, the former excited with nitric, the latter with dilute sulphuric acid, is a very powerful arrangement.

Two other batteries should be mentioned, viz., the Daniell and the Bichromate. Although perhaps not so well adapted for electric light as those above described, they are remarkably simple in construction and constant in action, giving a current of considerable strength.

Daniell's Battery (see Fig. 10) consists of an outside circular containing vessel of copper, which forms the negative element, the positive element being a zinc rod, held in an inside porous earthenware pot about half the diameter of the copper vessel. Two exciting liquids are required—a solution of one part of sulphuric acid to seven parts of water for the pot containing the zinc rod, and a saturated solution of sulphate of copper for the outside vessel. The battery is made more durable if the zinc rod is amalgamated with mercury.

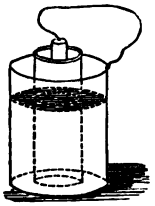


Fig. 10.

The Bichromate Battery consists of a plate of zinc for the positive element, and one or two plates of carbon for the negative element, which are usually connected to the wooden top of a glass containing jar. The exciting fluid is a solution of bichromate of potash in water, acidulated with about one-twelfth of its bulk of sulphuric acid.

The amount of chemical action in a cell is proportional to the quantity of current which passes through it, and is equal in each cell of a battery coupled up *in series*. When the circuit is broken, and the battery is doing no work, there should be no chemical action in the cells, but owing to the impurity of the ordinary commercial zinc used for battery plates, a **local galvanic action** takes place, and the zinc is wasted. To obviate this the plates are sometimes **amalgamated** or coated with mercury, which considerably increases their durability.

In coupling up batteries care should be taken to ascertain that each cell is in proper working condition, also that all connections are perfectly clean, and that good metallic contact is secured, so as to prevent any unnecessary resistance to the passage of the current.

CHAPTER IV.

Magneto-electricity. Action of Currents. Galvanometer. Principles of Dynamo Machines.

The method of producing electricity by means of the consumption of zinc in the galvanic battery described in the last chapter, is too expensive to be used for supplying the electric light except for experimental purposes.

To afford illumination on a practical scale, recourse must be had to the plan of converting mechanical into electrical energy by the machines termed **magneto-electric**, or **dynamo-electric generators**, often called for shortness, "dynamos." In order that the principle of action of these generators may be understood, it is necessary to trace the connection between what are called **magnets** and conductors conveying electric currents.

Lodestone or Magnetic Oxide of Iron is found in a natural state in many parts of the world. A bar of this material has the property of attracting iron and steel, and, when suspended in a suitable manner, of placing itself in a position pointing North and South, and is called a **natural magnet**. A piece of steel rubbed with a lodestone *permanently* acquires similar properties, and is called an **artificial magnet**. A piece of soft iron, whilst held under the attractive influence of a natural or artificial magnet, is found to acquire, *temporarily*, magnetic properties, which vanish when the iron

is removed from the influence of the magnet. This phenomenon is called **magnetic induction.**

The attractive power of a magnet is not equally distributed throughout its bulk, but is found to be much more intense at some points than at others. For example, when the magnet is in the form of a straight bar, the greatest attractive power is found to be located at two points at short distances from the ends. This can be shown experimentally by dipping a bar magnet into iron filings, which will be found to adhere in large quantities near the ends of the magnet, and to leave the centre bare (see Fig. 11).

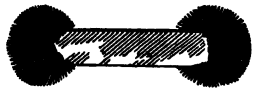


Fig. 11.

The end of a magnet which points to the north is called the **north-seeking pole**, and that which points to the south the **south-seeking pole.**

An ordinary compass needle is a convenient form of magnet for certain experiments. If the north-seeking pole of a magnet is brought near the north-seeking end of the compass needle it will be repelled, and the south-seeking end will be attracted. In other words, **like poles repel**, and **unlike poles attract** each other.

Magnetic attraction will take place through wood, glass, or any other non-magnetic material, but not through iron or similar magnetic substance.

The attractive power of a magnet is greatest close to its ends, and falls off rapidly as the distance from the poles is increased; for example, a magnet will attract any magnetic object one inch distant with four times the power exerted

at two inches, or nine times that at three inches distance. This fact is expressed by saying **that the attractive force of a magnet varies inversely as the square of its distance from the object attracted.** The force exerted by two magnetic poles is proportional to their separate strengths multiplied together, and varies inversely as the square of the distance between them.

The area round a magnet pervaded by the magnetic influence is called the **magnetic field.**

Lines of force may be considered as running from one pole to the other in curved lines. The direction of these lines may be investigated by placing a sheet of paper over an ordinary bar magnet, and sprinkling it with iron filings, which will be found to arrange themselves in curved lines, somewhat as shown in Fig. 12.

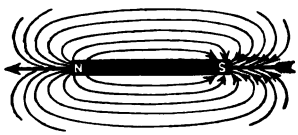


Fig. 12.

These lines show the direction in which a small magnetic needle would place itself at any given point under the influence of the attracting and repelling forces of the magnet poles. It may be convenient to consider the lines of force to flow from the north-seeking to the south-seeking pole, or in the same direction that a free north-seeking pole would travel.

There is a limit to the size and strength of magnets formed by rubbing with a lodestone or permanent magnet, which are not, as a rule, powerful enough for use in the machines generally used to produce the electric light, although some generators are still constructed with artificial magnets.

Another more suitable method of imparting magnetic power is to pass a current of electricity through an insulated wire wound in a spiral round a piece of soft iron (see Fig. 13). The iron will be converted into a magnet whilst the current is flowing, but will lose its magnetic power as soon as the current ceases.

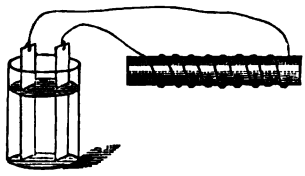


Fig. 13.

A magnet formed in this way is called an **electro-magnet.** If a piece of steel is used in the place of the iron it will not lose its magnetism when the current ceases, but will remain a permanent magnet.

The strength of an electro magnet depends on the number of turns of wire in the coil, and also on the strength of current which is sent round it. A cylindrical coil of wire through which a current is passed itself becomes magnetic, and is called **a solenoid.** It has the property, when suitably suspended, of placing itself in a position pointing north and south. It will also attract another solenoid or a magnet, having poles and lines of force and generally resembling an ordinary bar magnet.

If in Fig. 13 the current be supposed to flow round the iron core from the right to the left, *i.e.*, to flow round the bar in the same direction as the hands of a watch, then the end of the bar next to the battery in the figure will be the north-seeking pole of the magnet. Similarly, if the iron core is withdrawn, and the wire coil or solenoid has a current sent through it in the same direction as above,

the end of the coil next to the battery will be the north-seeking pole.

One of the properties of the magnetic needle is its inclination always to place itself at right angles to a conductor through which electricity is flowing.

The direction in which a current is passing through a wire can be ascertained by noting to which side the needle turns. For example, if when the needle is in its normal position a current is passed from north to south through a wire lying *beneath* the needle, the north-seeking pole will turn to the left hand or to the west, but if the current is passing from south to north it will turn to the right hand or to the east. If the current is passed through a wire *above* the needle the movements will be reversed.

The words NOSE and SNOW aid the memory as to the side the north-seeking pole will turn, thus: when the current is sent from

N orth	**S** outh to
O ver needle to	**N** orth
S outh it turns	**O** ver needle turns
E ast.	**W** est.

Taking advantage of these facts, an instrument, called a **Galvanometer**, has been devised by means of which the presence, strength, and direction of electrical currents can be ascertained. In its simplest form it is merely a magnetized needle, suitably mounted in a case or frame (see Fig. 14), and surrounded by a number of convolutions of insulated wire forming part of the circuit to be examined.

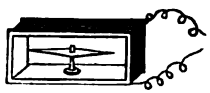


Fig. 14.

From the effect produced on the magnetic needle it may readily be inferred that a conductor conveying a current is surrounded by lines of force just as a magnet is. The direction of these lines of force (considering it, as in the case of the magnet, to be that which would be taken by a free north pole) is found to vary with the direction of the current. If in Fig. 15 the current flows along the wire from A to B, the direction of the lines of force will be right handed, as shown by the small curved arrow; or left handed if the direction of the current is from B to A. In other words, if a person looks along a conductor *in the direction in which the current is flowing*, the lines of force will flow round it in the *same direction as that in which the hands of a watch revolve.*

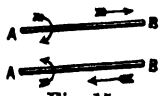


Fig. 15.

It has been stated that like magnetic poles repel, and unlike poles attract each other. In the same way, lines of force *flowing in the same direction repel*, and those *flowing in opposite directions attract* one another.

Thus the lines of force flowing between north and south magnetic poles (see Fig. 16) do not run parallel, but seem to mutually repel each other, and assume curved lines (see also Fig. 12).

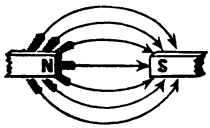


Fig. 16.

Two wires through which electricity is flowing in the same direction are found to attract each other, and to repel each other if the currents flow in opposite directions (see Fig. 15).

If the direction of the lines of force round the wires is examined, it will be noticed that in Fig. 17, which shows a section of two wires through which the current is flowing in the same direction (down through the paper), the direction of the adjacent lines of force (shown by the small curved arrows) is opposed, and consequently, as stated above, attraction results, and the two wires are drawn towards each other.

Fig. 17.

In Fig. 18, on the other hand, where the direction current in the wires is opposite, it will be noticed that the adjacent lines of force are now in the same direction, and consequently repel one another, and the wires are driven further apart.

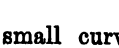


Fig. 18.

If a loop of stout wire be arranged so that it may be free to rotate upon its own axis between two magnetic

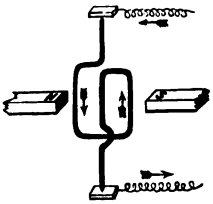


Fig. 19.

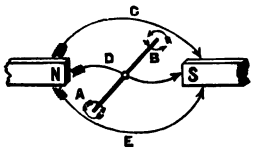


Fig. 20.

poles, and a current be passed through it down one side and up the other side as shown by the arrows in Fig. 19, it will be found to turn so as to place itself at right angles to a line joining the two magnet poles.

The lines of force which surround the wire act upon the lines of force between the magnetic poles, and distort them as in Fig. 20, which shows a section through the moveable wire loop, and in which for the sake of clearness, only three magnetic lines are shown, C, D, and E.

If the relative direction of the lines of force be examined, it will be seen that those round the wire A will be repelled downward by D and attracted downward by E, whilst those round the wire B will be repelled upwards by D and attracted upwards by C, the result being that these combined influences all tend to drive round the moveable loop of wire till it attains a position at right angles to the central line of the magnets, as shown in Fig. 21. If, whilst the loop of wire is passing the point indicated in Fig. 21, a current is sent through it in a reverse direction (*i.e.*, *up* the side A and *down* the side B), the direction of the lines of force round the wire will be reversed, and the side B will be repelled downwards and the side A upwards. In this way, by means of a suitable apparatus for reversing the direction of the current at every half revolution, a continuous rotation of the wire loop can be effected.

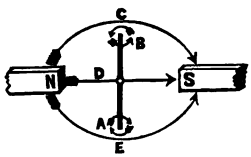


Fig. 21.

It has been shown above how the mechanical rotation of a wire conductor can be produced by passing a current through it whilst in a magnetic field. The converse of this also holds good, that is to say, if a loop of wire is

mechanically rotated in a magnetic field a current will be produced in it.

If, for example, the wire loop in Fig. 19 is caused to rotate between the magnet poles N. S. in the same direction as the hands of a watch, a downward current will be produced in each side of the loop as it passes before the N pole, and an upward current when it passes before the S pole as shown by the arrows in the figure, the direction of the current through the loop consequently being reversed at each half revolution.

In fact, whenever a conductor is moved near a magnet, so as to cut through lines of magnetic force, a current is generated. The effect is the same whether the conductor is made to approach the magnet or the magnet the conductor. Currents caused in this way are called **induced currents.** For example, a magnet can produce a momentary current in a coil of wire forming a circuit (see Fig 22). This occurs each time the magnet is introduced into or withdrawn from the coil. The current will flow in one direction when the magnet is introduced into the coil, and in the opposite direction when it is withdrawn. Such a current is produced every time a conductor is brought within the reach of the magnetic influence, and is called an **induced current.**

Fig. 22.

A current is caused to flow in one direction by the *approach* of the *positive* pole, or by the *withdrawal* of the *negative* pole of a magnet, and in the contrary direction if the poles are reversed.

An induced current can also be produced if a wire through which a current is passing is used instead of a magnet. This can be illustrated by arranging a wire forming part of a battery circuit so as to be parallel for a portion of its length to a second wire forming a circuit through a galvanometer (see Fig. 23). It will be found that every time the primary or battery circuit is broken or re-made, a current will be momentarily induced in the secondary circuit, and will be made manifest by the movement of the galvanometer needle. When contact is made, and the battery circuit completed, the induced current will flow in the reverse direction to the battery current, and when the battery circuit is disconnected and contact broken, the secondary or induced current will be in the same direction as the primary current was.

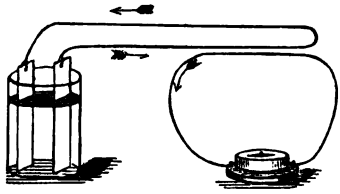


Fig. 23.

One other method of inducing a current should be noticed, namely, that when a coil of wire surrounds a soft wrought iron core, a current can be induced in it each time a magnet is made to approach to or recede from the core, this result is due to the magnetism alternately developed and destroyed in the core. In the same way, if a magnet surrounded by a coil of wire is brought near an armature, or piece of iron, its magnetism is affected, and a current is produced in the coil. The ordinary Bell telephone is an interesting example of this fact.

The above examples show the close connection that exists between magnets and conductors conveying electric currents, and the reversibility of their mutual action. The practical application of these principles to the construction of electric lighting apparatus will be described in the next chapter.

CHAPTER V.

Magneto-electric Generators. Dynamo-electric Generators.

The manner in which an electric current can produce mechanical motion in a conductor suitably placed in a magnetic field, and conversely the manner in which mechanical motion can be transformed into energy in the form of an electric current, has been explained in the preceding chapter. The principles therein stated are those on which all the modern electric generators and electro-motors are based.

The present chapter contains brief descriptions of a few of the better known generators, calling attention to the points which distinguish one from another, and in a subsequent page will be found further details of construction (such as the methods of winding the electro-magnets), applicable, not to a particular machine alone, but to all of a similar class.

The machines used for the production of the electric ight may be divided into two classes :—

I.—Magneto-Electric Generators.

II.—Dynamo-Electric Generators.

In the former machines permanent magnets are used, but in the latter electro-magnets, with soft iron cores

excited by passing round them an electric current produced either by the machine itself, or by a smaller adjacent machine provided specially for the purpose.

Shortly after Faraday's discoveries and investigations regarding magnetic induction were made public, a magneto-electric machine was constructed by **Pixii**, about the year 1833. In this machine a permanent magnet was caused to revolve closely before two coils containing soft iron cores, by the alternate magnetisation and demagnetisation of which a current was produced in the coils.

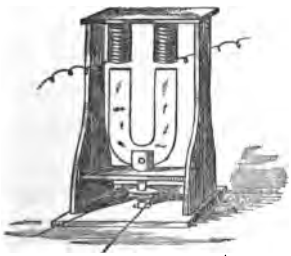


Fig. 24.

The mode of action of this machine is indicated in Fig. 24, which (like the other illustrations which follow) does not represent exact details, but is given simply as an illustration of the principle on which the machine works.

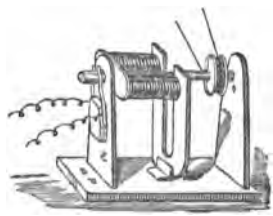


Fig. 25.

Shortly afterwards, **Clarke** introduced a machine in which the magnet was stationary and the coils revolved (see Fig. 25). This arrangement had the material advantage of reducing the weight of the moving parts.

In both the above machines the current induced in the coils is reversed in direction each time the polarity of the cores is reversed, which must necessarily take place

at every half revolution of the inducing magnet or of the coils.

To bring these alternating currents always into the same direction, an apparatus called a **commutator** is required.

It consists of two pieces of brass or copper, A and B (see Fig. 26), which are separated from one another by a strip of insulating material, and are fastened to the axis of the machine. One end of the wire passing round the coils is attached to A, the other end to B. Two springs, E and F, press against A and B, and by this means the current passes away from the machine through the conducting wire, G, completing the circuit, and returning to the machine by the conductor, H. During one half revolution of the machine the current flows to A and E, and through G and H back to F, and thence through B to the coils again. But when, during the second half revolution, the direction of the current is reversed, it flows through the coils from A to B, instead of from B to A as before. By this time, however, the revolving axis on which the coils are fixed will have carried round the commutator so as to bring B in contact with E, and A with F. The circuit is by this means always maintained in one direction, E G H F.

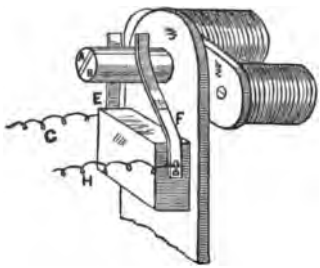


Fig. 26.

Although in all electric generators the rotating coils and the magnets before which they revolve do not touch one another (being arranged to pass as near as is practicable without fear of touching), yet considerable power is required to work the machines. This arises mainly from the resistance a magnetic field always offers to the passage through it of a conductor, forming part of a closed circuit. For example, if a copper disc is caused to rotate between the poles of an electro-magnet, it will be found that so long as the magnet is not in action the disc revolves freely, without resistance; when, however, the electro-magnet is excited by passing a current round it, the resistance offered to the revolution of the disc is considerable, and is sufficient to heat it. The stronger the magnet the greater is the resistance, and, consequently, the greater the power required to work the machine.

The generators of Pixii and Clarke described above were made with permanent magnets. The amount of power that can be imparted to magnets of this class is not great, and is found gradually to decrease with time, and it soon became evident that the efficiency of the machines would be increased if a more powerful magnetic field could be produced.

In 1845, **C. Wheatstone** suggested the substitution of an electro-magnet excited by a galvanic battery, in place of the permanent magnets used by Pixii and Clarke.

In 1854, **Hjorth** combined permanent magnets and electro-magnets in the same machine. The electro-magnets were excited by passing round them the current generated by the machine.

The construction of magneto-electric machines does not seem to have made much progress until about the year 1855, when the French Compagnie de l'Alliance was formed to undertake the manufacture of generators for electric lighting. The well-known **Alliance machines** produced by this company a few years later had no commutator, and therefore gave a current of alternate direction. These machines were composed of discs, built upon a central revolving shaft. Each disc was fitted at its outer edge with sixteen coils of wire, in which the current was generated by the inductive influence of permanent horse-shoe magnets arranged on fixed frames round the circles in which the coils revolved. Each machine had four or more discs, and a corresponding number of coils and magnets. Alliance machines of considerable power were used in the French lighthouses.

F. Holmes about the same time constructed somewhat similar machines in England. In his first designs the coils were fixed, and the magnets revolved, but in subsequent ones he adopted fixed magnets and revolving coils. Some of these machines were used in the South Foreland and other lighthouses, under the direction of the Trinity Board. All the machines described above were made with cylindrical coils, or bobbins wound round a central core.

De Meritens at the present time constructs both direct current and alternate current magneto-electric generators on a plan somewhat similar to the Alliance machines described above.

In 1856, **C. W. Siemens** introduced an improved form of **armature** (as the central revolving coil of a machine

is called), consisting of a long iron cylinder of small diameter, with deep grooves on each side in which the coils of wire are wound in a direction parallel to the axis of the cylinder (a section of this is shown in Fig. 27). The wire forming the coil is bound round at intervals with bands, to prevent it being displaced by the centrifugal tendency caused by the rapid revolution of the armature.

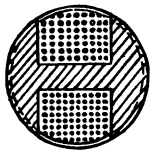


Fig. 27.

The small space occupied by this armature allows the poles of the inducing magnets to be brought very close together, with a corresponding increase in the intensity of the magnetic field. The small diameter of the armature also renders it possible to rotate it at a high speed with perfect safety.

Fig. 28 shows the general arrangement of a Siemens armature in a magneto machine. B B are iron pole pieces to which the permanent magnets, M, are attached, and packing pieces of brass, D D, make up the complete circle.

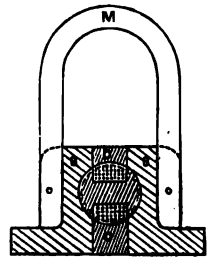


Fig. 28.

In the above machine (as in all other electric generators), the space between the magnet poles may be considered as occupied by lines of force (sometimes called tubes of force) passing from one pole to the other, and the wires forming the armatures of the machines have currents induced in them as they cut

through these lines of force. If, for example, in Fig. 28, the lines of force are supposed to pass from *the north pole on the left to the south pole on the right*, and the armature to revolve in the *reverse direction to the hands of a clock*, a current will be induced *from back to front* in each wire of the armature coil as it passes before the *north pole* of the magnet and cuts the lines of force *from above*, and in the reverse direction when during the next half revolution it passes before the *south pole* and cuts the lines of force from *below* The result being that at any given moment the current through the coil is continuous, passing on one side from back to front and on the other from front to back, the direction of the current being of course reversed at each half revolution of the armature.

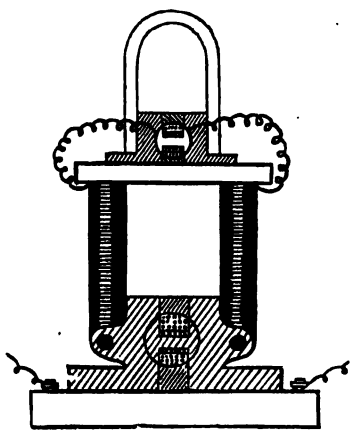


Fig. 29.

When it is desired to convert these alternate currents into one of uniform direction, a commutator must be used, the principle of which has been illustrated in Fig. 26.

Some years later, **Wilde** produced a very powerful machine (see Fig. 29), by using a Siemens permanent magnet machine to furnish the current to excite the electro-magnets of a larger machine, also constructed

with a Siemens armature; the smaller machine being provided with a commutator, so as to give a current of constant direction.

About the year 1867, **Siemens** and **Wheatstone**, working independently, introduced machines in which permanent magnets were entirely dispensed with. The magnetic field being produced by electro-magnets, the coils of which were arranged to form part of the main circuit of the machine; the **residual magnetism** (or feeble magnetic power always remaining in the soft iron cores) being sufficient to cause an initial current on th rotation of the armature, by which the force of the electro-magnets was strengthened. The mutual increase of power going on till the cores of the magnets reached the point of saturation, or, in other words, till they became incapable of acquiring any material increase of magnetic power. The idea of constructing dynamo machines with electro-magnets only, appears to have been put forward some years previously, but Siemens and Wheatstone seem to have been the first to reduce theory to practice in this respect.

Ladd's machine (date 1867) was constructed with a pair of powerful electro-magnets arranged horizontally, one above the other, and provided at each end with pole pieces containing a revolving Siemens armature. The current produced by one of these armatures was used solely to excite the electro-magnets, the other providing the current for the lamp.

Ruhmkoff employed a single armature wound with two separate coils, one of which was used to excite the

electro-magnet, and the other to supply the external working current.

Almost all the machines used at the present time for electric lighting are constructed with electro-magnets with soft iron cores. They may be divided into two classes :—

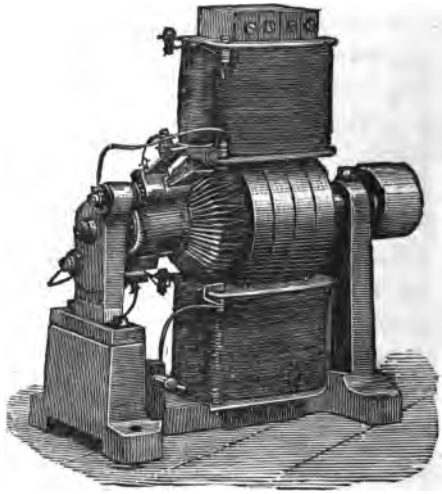


Fig. 30.

I.—**Direct current machines,** giving by means of a commutator currents in one direction only.

II.—**Alternate current machines,** giving currents which are constantly reversed in direction at intervals imperceptibly minute.

The following machines are described as types of those in most general use at the present time in this country :—

The Siemens direct current machine (see Fig. 30)

is one of the best known. It is not usually fitted with the grooved armature already described, but with one of improved form, consisting of an iron axis surrounded by a wooden shell wrapped with iron wire, on which are wound

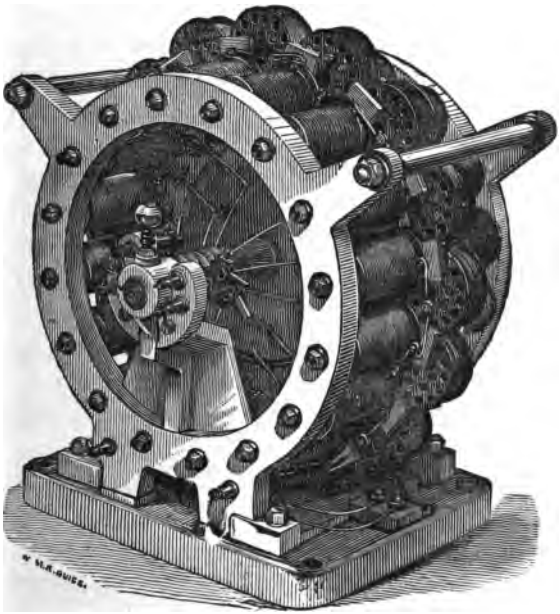


Fig. 31.

six or more coils of insulated copper wire so joined as to form one continuous length. The connection between the ends of the coils of wire is made by fixing them to radial copper plates, insulated from each other, and secured on the axis of the machine. Against these press the contact springs or brushes which lead away the current.

The method of coupling up the ends of the armature coils in such a way as to produce a current of uniform direction at the points at which the collecting brushes are placed is very ingenious, and was devised by **Von Hefner Alteneck**, in 1872.

The electro-magnets consist of curved wrought iron bars shaped to embrace the armature, and wound so as to cause the north poles of the magnets to be at one end of the horizontal diameter of the armature, and the south poles at the corresponding opposite point.

The Siemens alternating current machine (see Fig. 31) is constructed with a central disc, with bobbins of wire on its circumference. The disc revolves between the poles of electro-magnets which are fixed on two side frames, and point inwards towards the bobbins.

No iron cores are used in the bobbins of this machine, and though it is claimed that heat in working is thus avoided, there is probably a corresponding loss in inductive power.

The bobbins may either be used separately, each for a single circuit, or, if more strength of current is required, any number may be coupled up in series till the requisite electro-motive force is obtained, the ends of the wire of each bobbin, or series of bobbins, being connected to rings on the axis of the machine, against which collecting brushes press and lead the current to the lamps.

The electro-magnets of this alternating current machine are excited by one of the Siemens direct current machines already described.

The Siemens direct current machines are run at speeds

varying from 500 to 1,500 revolutions per minute, and will give lights varying from 500 to 12,000 candles at an expenditure of from 1½ to 7 horse-power. The alternate

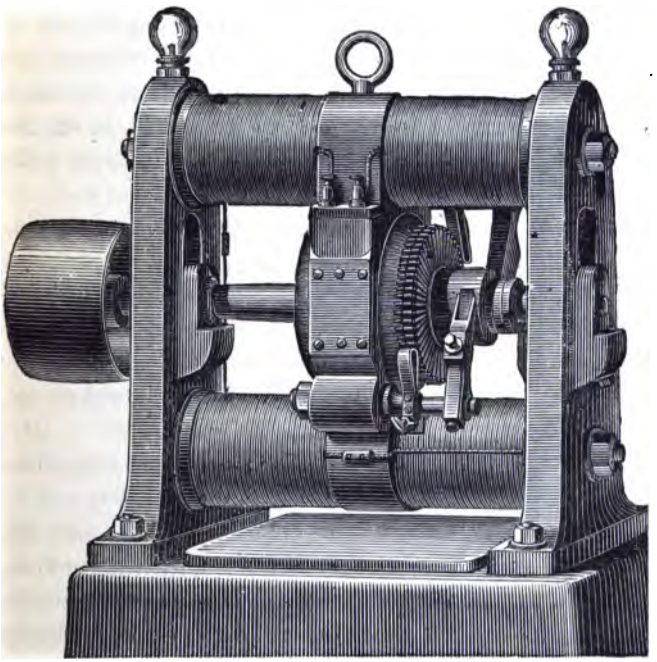


Fig. 32

current machines run at speeds of from 500 to 800 revolutions per minute, and together with the exciting machine require from 5 to 20 horse-power, according to size.

The Gramme direct current machine is illustrated in Fig. 32.

This machine, brought out in 1870, has the honour of having been the first machine able to produce on a practical scale a perfectly continuous current. The distinctive feature of this generator is the ring-shaped armature, the core of which is formed of a bundle of iron wires bound round with tape or canvas. Round the core are wound a number of separate coils of insulated wire. The ends of these coils are connected to copper strips fixed round the axis of the machine, every strip being united to one end of each of two adjacent coils, so as to form the whole of the coils into one continuous circuit.

Pacinotti, in Italy, many years previously had suggested this principle of construction, but the importance of his invention does not seem to have met with adequate recognition at the time, or to have been followed up by himself to any practical result.

Fig. 33 will illustrate the principle of this armature.

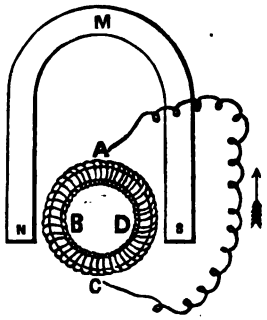


Fig. 33.

Owing to the inductive action of the magnet, M, upon the wire core, the ring may at any instant be considered to consist of two semi-circular magnets, having a pair of similar poles at B and at D, opposite each of the poles of the fixed magnet. Since the position of the poles does not move, but always remains opposite to the poles of the fixed magnet,

although the ring rotates, the action on the wire forming the coil is the same as if it rotated and the core remained stationary. The effect of the rotation of the armature being that in one-half of the ring the current is developed in the direction A B C, and in the other half of the ring in the contrary direction, A D C. Consequently, if the opposite points of the armature, or commutator, A and C, be joined by a conducting wire, a current of constant direction would be generated, passing from C to A, in the direction shown by the arrow in the illustration.

The portions of the coils which lie *outside* the iron core of the armature pass close to the magnet poles, and consequently have induced in them currents of considerable strength; the portion of each coil which lies *inside* the core would have an opposing current developed in it, if the lines of magnetic force passed direct across from north pole to south pole of the magnet.

It is found, however, that the interposition of the iron core practically screens off or diverts the lines of force, and thus prevents the induction of an opposed current. Also, if the iron ring is considered as a magnet, it would induce currents in the inside portions of the coils which would be in the same direction through the coils as those developed in the outer portions by the external magnets.

The electro-magnets are excited by passing round them the current generated in the armature. The armature ring when wound complete is fixed on to a wooden centre or support attached to the main axis of the machine.

The Gramme Distributor is a machine designed to divide a current into a number of separate circuits. It

consists of an outside fixed ring, divided into sections, on which are wound in alternate directions coils of covered wire. Inside this ring is the axis of the machine, from which project, like the spokes of a wheel, as many wide and flat electro-magnets (wound in alternate directions) as there are coils on the outer ring. These magnets are caused to revolve, and the current from an ordinary Gramme generator (see Fig. 32) is passed through the coils of the electro-magnets, which are wound so as to form one continuous circuit. These magnets induce an alternating current in the coils on the outside ring, which can be used either for as many different circuits as there are coils, or can be coupled up together if greater strength of current is desired.

Sometimes the Gramme exciter and distributor are mounted on the same framework, so as to form one complete machine. Each distributing coil consists of two wires wound side by side. If an intense current is required they can be joined end to end; or if a circuit of small resistance is wanted, the wires can be coupled up to the terminals side by side as they are wound.

For currents of considerable intensity and of *single direction* two Gramme machines are sometimes combined, the first being used simply to excite the electro-magnets of the second. A very powerful current can be produced by this arrangement.

The Brush machine armature is in the form of a ring similarly to that of the Gramme, but whilst in the latter machine the ring is wide in section and the magnet poles embrace its circumference, in the former it is made

deep in section, more like a disc, and the magnets are placed on each side. Spaces are left between the wire coils of the armature, which are wound in recesses sunk into each side of the ring. The ends of the coils in this machine are coupled up by joining the first and last ends of the opposite sections together, the two remaining ends being carried to insulated contact strips on opposite sides of the axle. Each pair of coils is connected in this way.

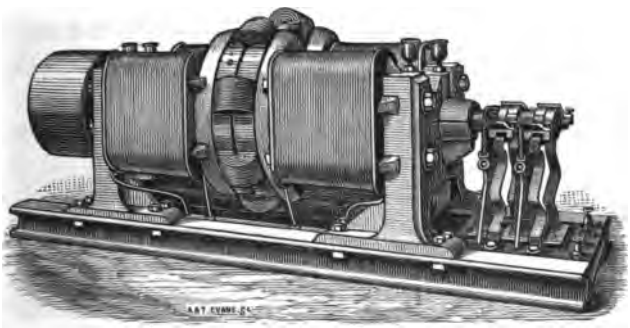


Fig. 34.

The collecting arrangement consists of as many separate discs or rings as there are pairs of coils, and each ring has two opposite portions insulated from the rest in such a way as to cut out of the circuit its pair of coils during the periods at which, twice in each revolution, they are passing through the least effective portion of the magnetic field. The resistance of the armature is in this way lessened, and the coils have, in each revolution, periods of rest which assist in keeping them from heating.

The electro-magnets are excited by the whole or part of

the armature current. In constructing this machine it is usual to wind a few layers of fine wire round the electro-magnets before the heavier wire is put on; by means of the fine wire a current is induced in the magnets irrespective of the main circuit. The large portions of the Brush ring uncovered by the coils assist in keeping the machine cool, even when the disc is revolving at high speed.

A large Brush machine, capable of maintaining 16 arc lights in circuit, with an external resistance of over 70 ohms, is stated to have an internal resistance of 4 ohms. The running speed is 700 revolutions per minute. About fourteen horse-power is required to drive it.

The Gülcher machine and the **Schuckert machine** are somewhat similar to the Gramme and Brush machines in general arrangement, but the pole pieces of the magnets are extended so as to embrace both sides and the circumference of the rotating coils of the armature. It is contended that in this way a greater portion of the wire on the armature is brought under the influence of the magnetic field.

The Maxim machine is very similar in appearance to the Siemens direct current machine, illustrated in Fig. 30. The armature, however, is entirely different, being cylindrical in form, with its coils wound inside and outside like the Gramme machine. The length of the armature, unlike the Gramme, is considerably greater than its diameter. The machine is furnished with collecting cylinder and brushes at each end of the axis. The field magnets are excited either by passing round them the current from the armature, or by the use of a separate exciter.

The Weston machine is noticeable for the form of its armature, which is built up of discs stamped out of sheet iron with gaps round the circumference to receive the wire coils. These discs are placed on the axis of the machine with separating washers, so that there is an air space between them which promotes the dissipation of heat. The pole pieces of the magnets have a series of slots cut in them, and are so formed as to embrace a larger portion

Fig. 35.

of the circumference of the armature at the ends than at the centre. It is claimed that by this arrangement greater steadiness of current is insured.

The Burgin or Crompton machine is constructed with horizontal field magnets. The cores of the upper and lower magnets are each cast in one piece, with ends of suitable shape for bolting together. The central portion of each casting, which forms the pole piece, is machined to receive turned cast iron covers, which form the framework in which the axis of the machine revolves. The armature (see Fig. 35) is built up of a number of

hexagonal frames of soft iron; each frame being wound with six barrel-shaped coils of wire, so that the complete coiled frame approximates to a circle in form. The frames are set one slightly in advance of another round the axis, so that the coils are arranged spirally, and are coupled up in series.

The resistance of the armature is about 1½ ohms and the E. M. F. at 1500 revolutions about 200 volts.

The field magnets are excited either by the main current or by a separate machine.

The Edison machine (see Frontispiece) is constructed of various sizes. The largest machine is driven at a speed of 350 revolutions per minute, by an engine of 125 horse-power, coupled direct on to its axis. The electro-magnets of this machine are arranged horizontally, and are of great bulk, the coils being about eight feet long, and producing an intense magnetic field. The armature, which is on the Siemens principle, instead of being wound with wire in the usual way, consists of solid bars of copper nearly half a square inch in section, and more than three feet long. The diameter of the armature is about two feet four inches, and the core is made up of sheet iron discs insulated from each other by paper. The copper bars are coupled up to the connecting drum by means of copper discs at each end of the axis, there being as many of these discs as there are copper bars. By this arrangement the resistance of the ineffective portion of the circuit, viz., that at the ends of the armature, is rendered extremely small.

The resistance of the whole armature is only eight

thousandths of an ohm, and of the electro-magnets 80 ohms. The machine produces an electro-motive force of 110 volts, and a current of 900 amperes. The armature weighs about 2½ tons, and the field magnets 10 tons, the total weight of the machine being about 17 tons.

The Lontin machine has an armature formed of a number of radiating iron cores fixed on a central axis. The cores, which are arranged spirally and wound with coils of insulated wire, revolve between the poles of electro-magnets excited by sending round them the current generated in the armature. **Lontin** has also **a distributing machine** of similar construction.

The Gordon machine is of large size, and is arranged to be driven direct by a steam engine at 140 revolutions per minute, without the intervention of gearing or belts. In this machine the electro-magnets revolve, and the armature coils are fixed to strong side frames. The central revolving portion which carries the magnet coils is built up of massive wrought iron plates about 9 feet in diameter, and weighs 7 tons. The magnets are excited by a separate adjacent machine. The total weight of the machine is about 18 tons.

The Elphinstone-Vincent machine has a drum-shaped armature formed of a mill-board cylinder, on which are placed flat wire coils. The magnetic field is formed between electro-magnets arranged round the outside of the drum and other similar magnets attached inside the drum to the fixed axis on which it revolves. In this machine all iron masses in the armature are avoided, and as the magnet poles can be brought very close together, a field of considerable intensity is produced.

The Ferranti machine has a thin disc armature composed of copper tape, which revolves between the poles of electro-magnets, arranged somewhat similarly to the Siemens alternate current machine. The small space occupied by the armature allows the magnets to be brought close together, producing an intense magnetic field.

There are many other dynamo-electric generators, but a sufficient number have been described to give some idea of the details of construction. In the following chapter, particulars will be found of the different ways in which the wire is wound on the electro-magnets to suit the various purposes for which the machines may be required.

CHAPTER VI.

Winding Dynamo-Magnets. Current Regulators. Measuring Instruments.

It will have been noted from the preceding chapter that the principle on which electricity is produced by dynamo machines is the same in all, viz., that coils of insulated wire are caused to cut through lines of magnetic force, thus inducing a current. It will also have been noticed that all the machines are based on the same principle, yet that the arrangement of the magnets, coils, and commutators may be varied in many ways.

It has been already stated that the iron core of an electro-magnet can be *saturated*, as it were, with magnetism, and that when this condition is reached its power cannot be materially increased, no matter what amount of current be sent round it for the purpose.

Hence it follows that there is also a limit to the current that the electro-magnets can induce in the coils of an armature revolving at any given speed. There is hardly any limit, theoretically, to the strength of the current which can be produced by increasing the speed of revolution of the armature coils. The speed is, however, limited, by practical considerations for the safety of the machine,

to about fifteen hundred revolutions per minute for the smaller machines, and a proportionally less speed for the larger sizes. The action of centrifugal force and the heating of the parts render higher speeds dangerous.

The nature of the current produced in the armature can be varied by selecting the wire with which the coils are wound to suit the work required.

In cases where a current of high electromotive force is necessary, the armature must be wound with *many turns* of wire which may be of small diameter. A small size of wire will cause a certain resistance to the passage of the current through the machine, which is then stated to have a large internal resistance.

On the other hand, when less internal resistance and a current of small electromotive force are desired, the armature must be wound with a *less number of turns* of wire of larger diameter, or, as in the Edison machine, wire may be dispensed with, and the armature be formed of solid bars of copper.

A very important point in the construction of a dynamo is the manner in which the exciting current is arranged to pass through the coils of the electro-magnets. The various ways of effecting this are as follows:—

I.—If the work the machine has to do is perfectly constant in character, opposing an uniform resistance to the passage of the current, as, for example, when a definite number of lamps are always in circuit, the magnets may be advantageously excited by either of the following plans:—

(*a*) By passing round them the whole current from the

armature, thus making the magnet coils form part of the main circuit, as in Fig. 36, where M represents the magnet, A the armature, and L the lamps or resistance in the external circuit. Machines of this class are termed "**series dynamos.**"

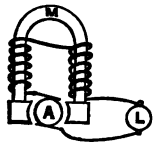


Fig. 36.

(*b*) By using a separate machine as an exciter (see Fig. 37). This method has the advantage over the one described above (*a*), viz., that the magnetic field is maintained at a uniform strength, even though the resistance of the external circuit should undergo accidental variation, and the magnets do not lose their power in the event of any momentary obstruction or interruption of the circuit. Dynamos wound on this plan are said to be "**separately excited.**"

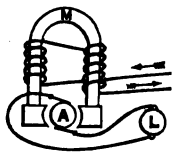


Fig. 37.

II.—In cases where the external work is subject to variation, it is better to resort to what is termed the *shunt* system of winding the magnets; that is to say, the plan of shunting off a portion of the main current to excite the magnets. This may be done in two ways—

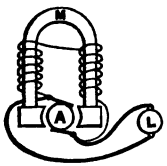


Fig. 38.

(*c*) By dividing the current as it leaves the armature into two branches (see Fig. 38), one for the magnets and the other for the external circuit. A machine onstructed in this way is called an "**ordinary shunt dynamo.**"

(*d*) By dividing the armature current into two branches, one of fine wire of high resistance which goes round the magnets only, and the other of larger wire which forms the external circuit, but which is also taken round the magnets (see Fig. 39). Machines arranged in this way are sometimes called "**compound shunt**" or "**self-regulating**" machines.

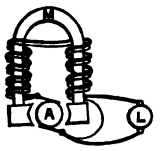


Fig. 39.

The principle and effect of shunt winding demands careful consideration. When a conductor along which electricity is passing is divided into two branches, the current will divide itself between them exactly in proportion to the facility of passage it finds. For example, if one branch offers twice the resistance to the passage of the current that the other does, only half as much electricity will flow that way as will pass by the less obstructed branch.

In this way, if it is desired to send round the electromagnet coils one-twentieth part of the main current, it will be necessary to select the wire with which these coils are wound of such a diameter and length as to give twenty times the resistance of the main circuit.

If, in the case of a number of lamps arranged in series, an extra lamp is added, and the resistance of the external circuit increased, a greater proportion of the current will be momentarily sent round the magnet coils, and the field will be intensified, and a current of higher electromotive force suitable for the increased resistance will be produced. The converse will take place if the resistance of the

external circuit is reduced. In each case the resulting current is automatically regulated to suit the work it is required to perform.

In the case of lamps worked *parallel* or *in multiple arc* (not in series), the resistance of the external circuit increases as the number of lamps is reduced (see Chapter IX.), and to meet this case recourse must be had to the compound shunt method (*d*). When this plan is adopted if the resistance of the external circuit is increased, more current will be sent round the fine wire magnet shunt, but less through the thick wire magnet coil, the result being that the magnetic force, and consequently the armature current, is suitably decreased. If, on the other hand, the number of lights arranged parallel is increased, the external resistance will be lessened, and the increased current round the thick wire of the magnets will more than compensate for the lessened current through the thin wire, the result being that in this case also the current is suitably proportioned to the work required of it.

In cases where an ordinary shunt dynamo (*c*) is used to supply a variable number of incandescent lamps arranged parallel, some method of regulating the strength of current must be adopted. This can be done in several ways, viz.:—

(i.) By switching into the main circuit a resistance equal to that of the lamps it is desired to turn out. This is a very uneconomical plan, as all the power used to overcome this resistance is absolutely wasted.

(ii.) By adding resistance to the magnet circuit, so as

to reduce the strength of the field in proportion to the lessened number of lamps. This may be done either by switching in resistances by hand, as in the Edison system, or by an automatic arrangement of electro-magnets and gearing as proposed by Lane-Fox.

(iii.) By the Brush system, in which a number of carbon plates are arranged to form a shunt circuit across the electro-magnets. The resistance of these carbon plates is lessened in proportion to the force with which they are pressed together by a lever, actuated by a pair of solenoids placed in the main circuit. When the main current is too strong, the carbons are pressed more closely together, and their resistance being lessened, they divert part of the current from the field magnets; the result being that the magnetic field is weakened, and consequently the strength of the main circuit current reduced. On the other hand, when the main current is too weak, the pressure on the carbon plates is lessened, more current is sent round the field magnets, and the main circuit current is correspondingly increased.

(iv.) By the Maxim system, in which the position of the collecting brushes on the commutator ring is altered by turning them round more or less from the position of greatest efficiency. This is effected by an arrangement of levers and wheels controlled by solenoids placed in a shunt circuit.

To produce the best results with any given dynamo, it is essential that the external and internal resistances should be properly proportioned to each other. Considerable assistance to this end may be derived by plotting out what

is called the characteristic curve of the machine, which may be done by varying the external resistance, and noting at each variation the electromotive force, and the strength of current.

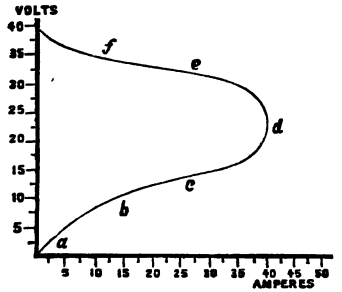


Fig. 40.

In the shunt dynamo, if the E. M. F. is marked off vertically, and the corresponding strength of current horizontally, the characteristic curve will be somewhat similar in appearance to the diagram in Fig. 40. At the portion of the curve marked A the resistance of the external circuit is so small that very little current is shunted round the magnets, and consequently they are not sufficiently excited to produce a current of any strength. As the external resistance is increased the curve takes the direction B C, till at D the maximum useful effect is produced. If the resistance is further increased, the E. M. F. may also increase till the magnets arrive nearly at the point of saturation, when the curve will become almost a straight line, as at E F, the strength of current in amperes gradually falling off as the resistance of the external circuit becomes greater.

It will be noted that the strength of the current in amperes becomes zero when the resistance of the exterior circuit is either very great or very small.

In the ordinary series dynamo, where the magnet coils

form part of the main circuit, the curve will be more like that shown in Fig. 41. When the resistance is small, and the magnets are saturated, the curve will be nearly flat, as at A B, but as the resistance is gradually increased both E. M. F. and strength of current will fall off, and the curve will take the direction C D E.

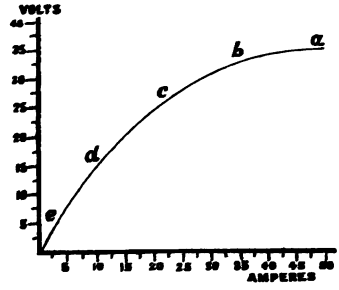


Fig. 41.

With a compound shunt dynamo the electromotive force remains practically constant, and the strength of current increases as the resistance of the main circuit is lessened ; the characteristic curve in this case approaching with more or less exactness to a straight line (see Fig. 42). In the above examples it is assumed that the speed of the dynamo remains constant, although the power required to drive it will of course vary with the varying strength of current and electromotive force.

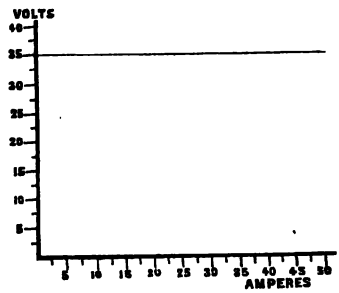


Fig. 42.

With respect to the instruments necessary to measure electrical currents in volts and amperes, the principle of

the **Galvanometer** has been described in a previous chapter. There are many very ingenious and sensitive instruments of this class, which, though admirably adapted for the special purposes for which they have been designed, are too delicate, and not sufficiently portable for practical use in rapid measurements.

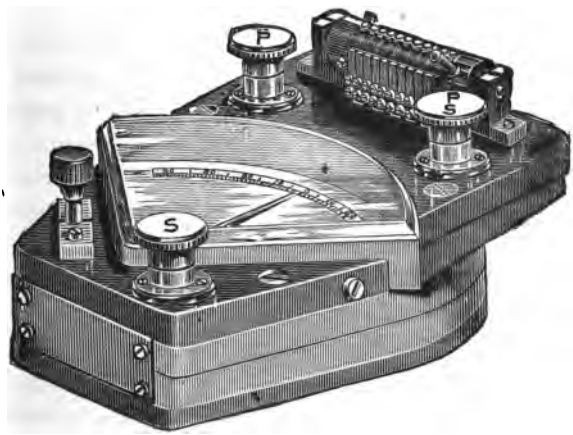


Fig. 43.

Professors Ayrton and Perry have, however, devoted their attention to the production of simple and portable instruments, by the aid of which measurements can be readily and accurately made of the currents used for the production of the electric light.

The Ammeter (see Fig. 43) is the instrument used to determine the *strength of a current in amperes.* A short soft iron needle is placed between the poles of a powerful

horse-shoe magnet. A very light aluminium pointer is attached to the needle working on an axis passing through their common centre of gravity. The movement of the pointer is observed on an index fixed on the top of the small flat box which forms the case of the instrument. The needle is surrounded by ten coils of wire attached to two terminal screws, to which the conductor, the current through which it is desired to measure, is also attached. A commutator is provided, by which, when measuring strong currents, the coils can be placed in parallel circuit, giving only ·005 ohm resistance, or in series, giving ·3 ohm resistance, when small currents have to be measured.

The instrument is provided with three binding screws marked S, PS, and P, as seen in the figure. The screw P is suitable for a thick wire, and S only for a thin, PS being suitable for either. Hence the wires from a dynamo, for example, can only be attached to PS and P, and not possibly to S. A current can only pass through the instrument from PS to P when the commutator is to parallel. Hence, if accidentally left to series, the circuit is merely interrupted, instead of the coils being fused or the pointer damaged by too large a deflection.

The needle and pointer being accurately balanced and maintained in place by the controlling influence of the strong permanent magnet, the instrument can be used in any position. The number of amperes equivalent to the movement of the pointer through one degree on the index being stated for each instrument, the calculation of the strength of any current is rapidly and easily made.

The Voltmeter, or instrument for measuring the

electromotive force of a current in *volts*, by ascertaining the difference of potential of two points in the circuit, is similar in construction to the ammeter, except that the coils are of very much higher resistance (in series 400 to 2,000 ohms), so as to tap off an almost inappreciable amount of the current it is desired to measure.

The following is an example of the method of using these instruments : If it is wished to determine the electrical horse-power in a given circuit, the ammeter must be arranged so as to form part of the circuit, and the terminals of the voltmeter must be connected to the terminals of the dynamo (or other source of electricity) to which the ends of the conductor forming the circuit to be measured are also attached. Then the reading of the ammeter in *amperes*, multiplied by the reading of the voltmeter in *volts*, divided by 746, will represent the horse-power electrically given in the circuit in accordance with the formula already stated, $HP = \frac{CE}{746}$.

All the instruments are so wound that, when a current is sent from the binding screw at one side to the binding screw at the other side of the commutator, the pointer points to that binding screw at which the positive current enters.

The ammeter and voltmeter are not suitable for measuring currents of *alternate* direction.

A Siemens Dynamometer may be used for this purpose. This instrument is constructed with two coils of wire, one of which is rigidly fixed, and the other is suspended around the first and at right angles to it. The current to be measured is passed through both the coils,

which by their mutual attraction endeavour to place themselves parallel with each other. The strength of current is determined by observing the degree to which it tends to deflect the moveable coil.

The above instruments are designed to test the electromotive force and strength of a current at the moment of observation, but do not afford the means of

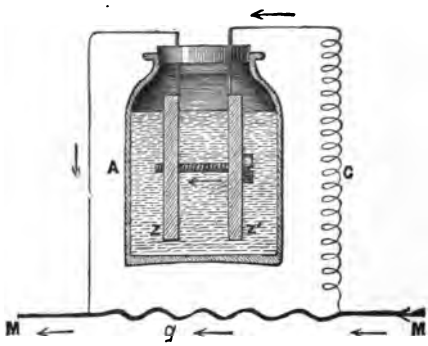


Fig. 44.

ascertaining the amount of electricity that has passed along a conductor in any given time. An instrument of this latter class is necessary if electricity for lighting, or other purposes, is to be supplied to consumers by measure in a similar way to the ordinary gas supply.

Edison's current meter (see Fig. 44), which has been devised to meet this requirement, is constructed as follows:—"In a glass jar, A, containing a solution of sulphate of zinc, are placed two plates of zinc, z z, the weight of which has been carefully ascertained; a very

small wire, G, is branched off from the main, M M, supplying the house, and connected to one of the zinc plates; another wire passes from the second zinc plate back to the main, thus forming a shunt circuit through the jar. The shunt wire is so proportioned to the main wire as only to be capable of conveying $\frac{1}{870}$ part of the current. The current passing through the jar causes the decomposition of the first plate of zinc, and the gradual deposition of zinc on the second plate. This decrease and increase is exactly in proportion to the amount of current which passes, and which can therefore be ascertained by weighing the plates at any given periods, and this amount multiplied by 870 will represent the total amount of electricity supplied through the main wire.

The above instrument gives the amount of current in coulombs that has passed through it in a given time, but does not record in any way variations in electromotive force. If a constant difference of potential can be maintained in the electrical supply mains, the current meter would answer every purpose; but it is not adapted for ascertaining the electrical energy of a current of varying E. M. F. passing along a conductor at a given time or during a given period.

The Ayrton and Perry Ergmeter is a self-registering energy meter. It consists of an ordinary pendulum clock, possessing a seconds hand. The pendulum bob is formed of a coil of fine wire of high resistance; fixed on the case of the clock is a coil of thick wire, through which the main current passes, whilst the fine wire coil is traversed by a shunt circuit. The mutual attraction of the coils tends to

retard the action of the clock, which, consequently, loses time, and the quantity of electrical energy equivalent to a given retardation of the clock having been once determined, the electric power supplied through the meter in any given period is easily calculable.

The Siemens Wattmeter consists of a fixed coil of German silver wire of high resistance, round which (and at right angles to it) a coil of one turn of thick wire is suspended by a torsion thread. Above the coils is an index dial, upon which two pointers indicate the amount of torsion caused by the deflection of the moveable coil. The main current passes through the thick wire, and the fine wire coil is arranged as a shunt circuit to the lamp or other absorber of power, the supply of which it is desired to measure. A table is supplied with the instrument showing the number of Watts equivalent to any given degree of torsion.

CHAPTER VII.

Arc Lamps. Candle Power. Photometers. Details of Lamps.

The illuminating power of the electric light or of gas is usually expressed by the number of standard candles which would give an equivalent light, and these lamps are specified as being of 10, 20, 100 or 1,000 candle-power, as the case may be.

In this country the **Standard Candle** is made to burn as nearly as possible 120 grains of spermaceti per hour. In France the **Carcel Lamp,** burning 648 grains of pure oil per hour, and equal to about 7½ candles, is taken as the standard measure. Gas used in a burner, consuming 5 cubic feet per hour, gives a light of about 16 standard candles.

To compare the power of two lights, an instrument called a **Photometer** must be used. In its simplest form it consists of a white paper screen, which can be moved along a graduated scale, at the ends of which the two lights to be compared are placed. A spot of grease is made in the centre of the screen, which is moved along the scale till the point is found at which the grease spot

cannot be distinguished from the other portion of the surface of the screen, this being an indication that the illumination of each side of the screen is equal.

The distance of each light from the screen is noted by the scale, and the *proportion of the illuminating power of one light to the other will be inversely as the square of its distance from the screen.*

For example, if the scale is 5 feet long, and uniform illumination is obtained at a point 3 feet from one end and 2 feet from the other, the relative powers of the lights will be as 2^2 to 3^2, or as 4 to 9; the more powerful light, of course, being the one that is furthest away from the screen.

Arc lamps are the most powerful of the various classes of lamps used for electric lighting. The principle on which they work may be shortly described as follows:—If a conductor along which electricity is passing is cut in two, and the ends are slightly separated, the current will cross the space so formed. The break, however, offers great resistance to the passage of the current, and intense heat is produced, the heat generated in any portion of a circuit being always proportional to the resistance of that part. If a stick of carbon is so arranged as to form part of a circuit, and if whilst the current is flowing the carbon is broken in two and its ends are drawn a very short distance apart, a luminous arc of great brilliancy (called the **voltaic arc**) will be formed at the break. A small quantity of carbon is volatilised, and the light is caused partly by this intensely heated carbon vapour, through which the current flows from one point to the other, and

partly by the extremely high temperature of the carbon points themselves.

The two pieces of carbon used in **Arc Lamps** are sometimes called electrodes. The upper carbon in Fig. 45 is the one through which the current first flows, and is called the positive electrode, or carbon, and the lower one the negative. The positive carbon is found to burn away twice as fast as the other, and to become concave or hollow at the end, whilst the negative carbon maintains a pointed shape. The positive carbon is usually placed uppermost, as in the figure, because its hollow end when the lamp is at work acts as a kind of reflector to throw the light downward. To maintain uniform illumination some arrangement is required for bringing the carbons nearer together as they burn away, thus keeping them always at the same distance from each other. Many self-adjusting arrangements have been devised for this purpose. In most of these the carbons are attached to guides combined with trains of wheels, which push them forward at the necessary speed. The wheels are put in action or stopped, as the case may require, by means of electro-magnets forming part of the electrical circuit of the lamp. Most of these electric lamps, or regulators, as they are termed, are arranged so that when the lamp by any chance goes out, the carbons are brought into contact for an instant, and, the current being in this way

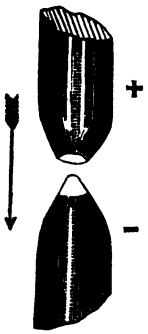


Fig. 45.

re-established, they are again drawn back to the required distance.

When arc lamps are worked by a machine giving currents of alternate direction, both carbons burn away at the same rate, the end of each maintaining a pointed shape.

In the earlier experimental exhibitions of the electric light, the distance of the carbon electrodes was regulated by hand. No satisfactory practical results could be attained by this method, and as early as 1847 **Staite** contrived a mechanical method of regulation. In his lamp the upper carbon was stationary, and the lower one was fed upwards as required by means of a screw on its holder, actuated by a train of clockwork, which was controlled by an electro-magnet forming part of the main circuit. In a subsequent design the lower carbon was raised by a cord and weight, the movement being governed by a solenoid surrounding the lower carbon-holder. When the carbons burnt away, and the distance between them became too great, the current through the solenoid and its attractive power decreased, and allowed the carbon to rise to the proper position, at which point the power of the solenoid was re-established, and the further rise of the carbon-holder prevented.

Staite also invented a lamp in which the lower carbon was raised by means of a float attached to its holder, and immersed in a vessel filled with liquid. The idea of using a float had been put forward by inventors previously, and has been reproduced at a later date, but does not appear ever to have met with any practical success.

Foucault and Duboscq brought out lamps in which the carbons were made to approach each other by trains of wheels driven by springs. The action of the clockwork was regulated by a detent controlled by an electro-magnet, which checked the movement of the carbons when the current became too strong and the length of arc too small.

Archereau, about the year 1849, devised a lamp in which a solenoid coil surrounded the lower carbon-holder, and drew apart the carbons till the proper length of arc was reached. A counterweight was employed to raise the lower carbon when the carbons were too far apart and the action of the solenoid was correspondingly decreased.

Gaiffe's Lamp is very simple in construction. The upper and lower carbon-holders are provided with racks, which gear into a pair of pinions fixed on the same axis as a spring barrel, which causes them to rotate. This barrel is wound up by separating the carbon-holders, which are carefully balanced, and the power of the spring can be varied by a key as required. The lower holder is continued towards the base of the lamp, and passes within a solenoid, the coils of which increase in thickness from top to bottom. When the lamp is not at work the carbons are in contact, but when the current passes the solenoid draws down the lower holder, thus separating the carbons sufficiently to form an arc. If the current is interrupted, the carbons are again brought together by the action of the spring.

The pinion into which the rack of the upper carbon-

holder works is made twice the diameter of that which gears with the lower carbon-holder, and in this way the speed at which each carbon is fed forward is exactly proportional to the rate at which it burns away. The current passes from the dynamo to the upper carbon-holder and carbon down through the lower carbon and holder, and thence through the coil of the electro-magnet back to the generator, as shown by the arrows in Fig. 46.

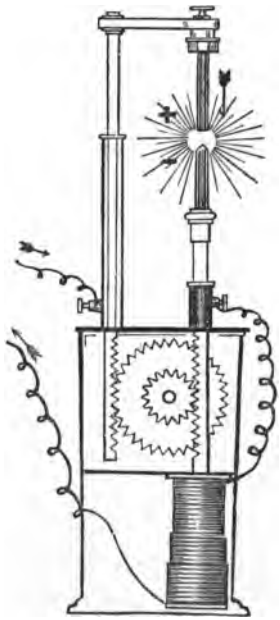


Fig. 46.

In the **Serrin** lamp the upper carbon-holder is fitted with a rack which gears into a pinion forming part of a train of wheels. On the same spindle is fixed a drum, on which is wound a chain by which the lower carbon-holder is raised. The upper holder is heavier than the lower, and provides the requisite motive power. The last wheel of the train is star-shaped, and can be stopped by a catch fixed to an oscillating frame controlled by an electro-magnet. When the current passes, the catch is thrown into gear, and the movement of the carbons prevented until the arc becomes

too long. When this takes place, the electro-magnet loses its power, and the catch is withdrawn by a spring, and the carbons are allowed to approach each other.

In the **Siemens Pendulum Lamp** the lower or negative carbon-holder is fixed, the upper carbon-holder being fitted with a rack which, when falling to bring the carbons closer together, causes a pinion to rotate. An escapement wheel and pendulum checks the speed of revolution of the pinion. When the lamp is at work, and the carbons the proper distance apart, they are kept from moving by a small lever which stops the movement of the pendulum and train of wheels. When the carbons burn away, and the arc becomes too large, and the current consequently too weak, the small lever (which has been kept in place by the action of a solenoid or magneto-electric coil) is allowed to fall, and the pendulum, pinion, and upper carbon-holder are free to move till the distance between the carbons has been sufficiently diminished.

These lamps, and all others in which the strength of the current directly regulates the distance of the carbons in a similar way, are generally worked singly, that is to say, with a separate circuit for each lamp.

Siemens Differential Lamp, Fig. 47, has been devised to obviate this difficulty. The small lever which checks the movement of the regulating pendulum is controlled by the action of *two* solenoids. One of these is in the main circuit of the lamp, and acts in the same way as the controlling solenoid in the simple pendulum lamp, the other is composed of fine wire

of higher resistance, the ends of which are connected direct to the terminals of the lamp, thus forming a shunt circuit, or second way for the electric current to pass without going through the carbons.

Fig. 47.

The action of the main solenoid tends to separate the carbons. When they get too far apart the greater resistance offered by the main circuit causes a greater portion of the current to be diverted to the solenoid in the shunt circuit, which tends to bring the carbons nearer together again. It is unnecessary to describe the exact details of the mechanism by which the above actions are effected, but it will be clear from what has been said that the current can always pass through the lamp by one or other of the paths provided. When the carbons are burnt out a short circuit shunt is brought into work by the action of the high resistance solenoid, and forms a path for the current to the other lamps. A

large number of lamps of this class can be worked in one circuit. When the two lamps just described are made with a fixed lower carbon-holder, the voltaic arc of course descends while burning, but in cases where it is required to keep the arc constantly at the same point, **Siemens' abutment pole** is added, and the lamps are then called *focus-keeping*. This arrangement consists of a tube to contain the lower carbon, which, as it burns away, is pushed upwards by a balance weight or spring, against a fixed abutment or copper ring of slightly smaller diameter than that of the carbon.

In the **Brush Lamp** the lower carbon-holder is fixed, and the upper one passes through a loose circular washer or collar, through which, when in a horizontal position, it can slide easily. This collar, however, when lifted on one side by a projecting hook attached to the cores of two solenoids, is tilted out of level sufficiently to cause it to grip the carbon-holder and raise it, thus causing an increase of space between the carbons.

This lifting takes place when the current passing through the solenoids attains a sufficient strength to lift the core, and this occurs whenever the carbons are too near together, and the space between them does not offer sufficient resistance to the passage of the current. On the other hand, when the carbons are too far apart, the current through the solenoids is weakened, and the core with its hooked end falls and allows the collar to resume its horizontal position, enabling the upper carbon-holder to slide freely through it, and bringing the carbons again sufficiently near together. The exact method of action is as follows :—

The regulating solenoids are wound with two coils of wire, each forming part of the main circuit, which is in this way provided with two paths through the lamp. The first coil is of thick wire, and conveys the current to the carbons. The second coil is of fine wire, forming a shunt circuit of high resistance between the terminals of the lamp, and is so wound that the current passes through it in the opposite direction to that in the thick wire coil.

By this means, when the carbons are too far apart, a larger proportion of the current is shunted through the fine wire and counteracts the power excited by the thick wire coil, and the solenoid losing its power, the core falls, and the carbons approach each other. When, however, the carbons are too near together, the reverse action takes place as stated above.

Lamps constructed with this arrangement of checking and lifting the carbon-holders are called **Clutch Lamps.** The regulating apparatus is very sensitive in action, and the upper carbon-holder in practice slides with a steady movement through the clutch, at the rate requisite to compensate for the gradual burning away of the carbons.

The **Weston Lamp** is constructed on a similar principle to that described above, but the clutch is formed by a lever attached to a swinging frame, forming the armature of two electro-magnets, wound as in the Brush lamp, with two coils in opposite directions, one leading to the carbons and the other forming a shunt circuit between the lamp terminals. To prevent any sudden jumping of the clutch mechanism, the movement of the armature is restrained by a perforated piston working in a small closed cylinder containing glycerine.

In **Crompton's Lamp** the positive carbon-holder is fitted with a rack which actuates a train of wheels. The lower carbon-holder is kept in position by a spring, and has attached to it the armature of an electro-magnet through which the lamp current passes. When the carbons approach too near together, the electro-magnet pulls down the armature and the lower carbon against the action of the spring, and at the same time the revolution of the train of wheels is arrested by a catch fixed to the armature, which is brought into contact with the last wheel of the train.

The Brockie Lamp is worked in connection with an automatic commutator driven from the shaft of the generator. By means of this commutator the circuit is momentarily broken at fixed intervals, and in this way the carbons are allowed to fall into contact, being instantly drawn back to the desired length of arc by the action of an electro-magnet and clutch. Another form of Brockie lamp is regulated by two solenoids, one of which in a shunt circuit controls the feeding arrangement, and the other in the main circuit varies the length of arc proportionately to the strength of current.

The "Pilsen" Lamp, designed by Messrs. *Krizik and Piette*, has two regulating solenoids placed vertically one over the other. They are both in the main circuit of the lamp, one being wound with wire of higher resistance than the other. The iron core which passes into both solenoids is not a solid cylinder, but contains more metal at the centre than at the ends. The peculiarity of a core of this shape is that it will maintain a stable position at

any point in its range, being in this respect unlike a cylindrical core, which tends always to take up a position varying with any change in the relative power of the solenoid coils. The spindle-shaped core forms part of the upper carbon-holder, which is allowed to fall when the current becomes weakened by the too great length of the arc, and is held stationary by the attraction of the solenoids when the length of the arc is sufficiently reduced. These lamps are also fitted with an electro-magnet, which automatically shunts off the current when the carbons are burnt out.

In the **Gulcher Lamp** the upper carbon is allowed to fall by the force of gravity till it touches the lower carbon. At this point an electro-magnet mounted on trunnions is brought into action; one end of the magnet is attracted downward to an armature block on the casing of the lamp. This movement causes a corresponding upward movement of the other end of the magnet, and of the upper carbon-holder with which it is in contact, and the arc is formed.

When the distance between the carbons becomes too great, and the magnet loses its attractive power, the upper carbon again falls by its own weight, and the above operations are repeated.

The Wallace Lamp carbons are not circular rods, but flat plates, between the edges of which the arc is produced. The lower carbon is fixed, and the upper one is attached to a brass rod which slides through the centre of an annular clutch, actuated by an electro-magnet, as in the other clutch lamps already described.

In the **Hedges Lamp** two carbons are fixed in troughs at an acute angle, and allowed to slide together by their own weight. They are separated by the action of a solenoid in the main circuit, and an electro-magnet in a shunt circuit regulates the length of the arc.

Rapieff's Lamp has four carbons, which are arranged in pairs, two above and two below the arc, in the centre of which they meet. Each pair forms an acute angle like the letter V. A weight and cords are arranged to bring the carbons together, and when the current passes an electro-magnet draws one pair of the carbons back the requisite distance.

The Heinrichs Lamp carbons are ring-shaped pencils (each being a half circle) held in hinged holders. The positive pair of carbons form a complete circle, and the negative pair another circle at right angles to it. The two rings are arranged to be close together at their lowest points, where the carbons join, and the arc is formed between them. The hinged holders allow the carbons to fall together as they burn away.

All arc lamps should have complete surrounding globes, protected with a wire netting, and each lamp should be provided with a switch or cut out.

There are many other lamps of this class, but for the most part they resemble one or other of those already described as to details of construction.

The power required to work arc lamps varies very much with the size of the carbons, the details of construction, and the amount of current supplied to the lamp. For the smaller sizes of lamps an illuminating power equal to

1,000 standard candles may be obtained for the expenditure of one indicated horse-power, but with lamps of 3,000 to 5,000 candle-power more economical results can be attained.

The process of manufacture of the carbons used for arc lamps will be described in the next chapter.

CHAPTER VIII.

Electric Candles. Semi-incandescent Lamps. Incandescent Lamps.

Electric Candles, as they are termed, are a modified form of arc lamp, in which all regulating mechanism is dispensed with.

The Jablochkoff Candle is the best known of these lights, and is constructed as follows :—

Each candle consists of two small strips of carbon about one-sixth of an inch in diameter and nine inches long, which are separated from each other by a narrow insulating strip composed of sulphate of lime and baryta. The bottom ends of the carbons are fixed in copper tubes which fit into sockets in the lamp. The top of the carbons are electrically connected by a small pencil of carbon, or more simply by dipping them in a solution of gum and plumbago. The candles require a current of alternating direction, which maintains an electric arc across the top of the carbons. The insulating material is gradually consumed together with the carbons, which burn away as an ordinary candle does. Four pairs of carbons are usually enclosed in a glass globe, the current, as each is consumed, being switched from one pair to the next, either by an attendant, or by an automatic arrangement set in action by the heat caused by each candle when burnt down.

Wilde's Candle is somewhat similar in arrangement, except that there is no insulation between the carbons. It is self-lighting, a hinged holder being provided for one carbon, allowing it, when the current is not passing, to lean against the other. The hinged holder and carbon are drawn into a vertical position by an electro-magnet directly the current passes.

In **Rapieff's Candle** the carbons have no insulation, but are inclined towards each other so as to be in contact at the top, and a slight distance apart at the base. It has a self-lighting arrangement, actuated by an electro-magnet.

Jamin's Candle is formed of two carbons without insulation, which are arranged to burn in an inverted position. The arc would naturally have a tendency to rise to the upper ends of the carbon, but this is prevented by winding the conducting wire one or two turns, in the shape of a rectangular frame, round the carbons from top to bottom, which is found to have the effect of keeping the arc at the lower extremity of the carbons. To facilitate lighting, the points of the carbons are temporarily held together by an elastic band, which is destroyed on the first passage of the current, and allows the carbons to resume their parallel position.

The Andrews Lamp has electrodes formed of two flat carbon plates placed about one-eighth of an inch apart, and having between them a thin plate of plumbago, from which they are insulated by strips of slate. The arc is formed at the top edge of the carbons across the plumbago plate. It has a self-lighting apparatus, consisting of a

piece of carbon on a hinged brass arm, which is momentarily brought into contact with the carbon plates by an electro-magnet whenever it is necessary to re-establish the arc.

Semi-Incandescent Lamps hold an intermediate position between arc and incandescent lights. In these lamps, for the most part, a carbon rod is caused to press against a block of carbon, or of some other material that can be heated to a condition of incandescence. The light is produced by the intense heating of the rod of carbon close to the point of contact, and also where the pressure is slight by small arcs formed immediately around this point.

Regnier's Lamp comprises a rod and a disc of carbon. The rod as it falls communicates motion to the disc, which is thus caused to revolve and to continually present fresh points of contact.

In **Werdermann's Lamp** a rod of carbon is forced upwards by the action of a weight against a rounded block of carbon. The rod becomes incandescent at its extremity, and gives a clear strong light.

The Sun Lamp (or *lampe soleil*) is so arranged that a block of marble is kept in a state of incandescence by the passage over its surface of a current of electricity flowing from one carbon to the other.

The carbons used for electric lamps of whatever kind should be selected with great care, and must be, as far as possible, uniform in structure, since the quality of the carbon is found to have a very marked effect on the illuminating properties of the light.

Carbons differ in size with the kind of lamp or candle and vary from one-sixteenth of an inch to one inch, diameter, according to the class of light required.

The carbons were at first formed of lumps of deposit found in gas retorts, but now they are usually made by reducing coke or graphite to a very fine powder. The material is then mixed up with saccharine, or other matter into a kind of paste, rolled into rods of the required size, and then baked at a very high temperature. Carbons are made in any length up to about three feet long. They are occasionally coated with copper to give them greater conductive power.

Carbons are sometimes made with a small central core of softer composition, which is said to increase the steadiness of the light.

Incandescent Lamps. When an electric current passes through a conductor of small sectional area and high resistance, intense heat is generated. If the conductor is formed of thin iron wire, it will be heated to redness; or if a strip of carbon of equal size be substituted for the wire, it will be raised to a greater temperature, because it is a worse conductor, and, if in ordinary air, will be at once burnt up. If, however, the experiment is performed in a vacuum, the carbon will not be burnt, but will merely be heated intensely and become incandescent.

Lamps constructed on the above principle are termed **Incandescent Lamps**, and are, for the most part, very much alike in appearance. They usually consist of small glass globes, from which all air has been exhausted, and

containing a small filament of carbon of curved form. The ends of the carbon strip are connected to conducting wires, which are fused into, and pass through, the lower portion or stem of the glass globes.

Experiments have, from time to time, been made to construct incandescent lamps with *metal* filaments (platinum and iridium being usually selected as most suitable), but up to the present time no real success has been achieved in this direction, and carbon still remains the most efficient material for the purpose.

Although the principle of all the incandescent lamps is the same, they differ from one another in the shape and mode of preparation of the carbons, and the method in which the conducting wires are attached.

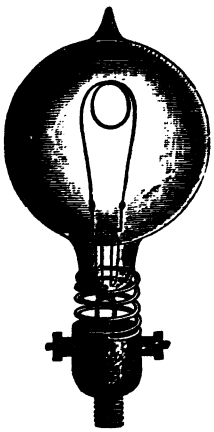


Fig. 48.

The lamps in most general use in this country at the present time are the Swan, Edison, Maxim, and Lane-Fox, the leading characteristics of which are described below.

The Swan Lamp and holder are illustrated in Fig. 48. The carbon is formed from cotton thread, treated with a solution of sulphuric acid till the fibre of the cotton is destroyed, and reduced to a perfectly homogeneous condition. The filament is next washed, dried, and carbonised, and fixed in a glass globe from which the air is very carefully exhausted. The finished carbon is in the shape of a

loop with a double turn at the top (see Fig. 48); the ends of the carbon are fixed into sockets formed in the ends of the platinum conducting wires. The lamp-holder is made of ebonite, and has a spiral spring socket to receive the glass globe, and two little metal hooks which connect with the looped ends of the platinum wires of the lamp. The holder is provided with two binding screws for the attachment of the service wires which supply the current, and its lower end has a taper screw cut on it of suitable size for fixing to the fittings ordinarily used for gas. Swan lamps are made of various sizes and illuminating power, varying from 2½ to 100 candles.

Fig. 49.

The Edison Lamp carbons are formed from bamboo cane, which is cut into strips bent round into the shape of the letter U, the ends being left thicker than the central portion. The bent pieces of bamboo are then placed in grooved metal moulds and carbonised in a furnace. The filament is connected to the conducting wires by copper chemically deposited. The air is exhausted from the glass globes by a mercury pump. The general appearance of the lamp and holder is shown in Fig. 49. The base of the globe is fitted with a central copper disc, to which one of the conducting wires is attached, whilst the other is fixed to an external metal screw insulated from

the disc by a layer of plaster of Paris. When the lamp is screwed into its socket the disc is pressed against a similar insulated metal plate at the bottom of the socket, and the external screw makes contact with the internal screw of the socket, the service wires being connected respectively with the internal screw and metal plate. The Edison lamps are for the most part made in two sizes, giving an illumination equal to eight or sixteen candles.

The Maxim Lamp filament is shaped like the letter M, and is formed of a strip of carbonised paper, which is further coated with a fine deposit of carbon by being heated in a closed chamber containing gasoline vapour. The filament is rendered incandescent by passing a current of electricity through it, and as the thinnest portions are necessarily most heated, they receive a proportionately larger deposit of carbon, till the filament becomes of uniform section and resistance throughout. The illuminating power of the Maxim lamp is usually from 30 to 50 candles.

The Lane-Fox Lamp has a carbon filament of horse-shoe shape connected to the platinum conducting wires by small spirals at their ends. The fibre from which the filament is made is the root of an Italian grass, which is carbonised in a crucible, and strengthened by a deposit of carbon formed by passing a current through it when enclosed in a vessel containing hydro-carbon gas.

The lamps are made of various illuminating powers.

The amount of mechanical energy requisite to supply electricity for incandescent lamps is about one horse

power for every 200 standard candles. The above power may be arranged to produce 20 lamps of 10 candles each, or 10 lamps of 20 candles each, the total result in each case being a light equivalent to 200 candles.

In calculating the indicated or actual horse-power required to work any given number of lamps, an allowance should be made for the power lost by the friction of the generator and of the prime motor. This loss may amount to 10 per cent., or more, of the indicated power, and therefore it is prudent to reckon on only eight or nine 20 candle lamps per horse power instead of 10. When worked with a full amount of current, incandescent lamps may be made to produce even 300 candle power per horse-power, but with corresponding decrease in the durability of the lamps, and under ordinary conditions, the average assumed above is as high as can be fairly taken for the lamps at present in use.

The illuminating power of an incandescent lamp can be made greater by increasing the length and resistance of the carbon filament, but the power required to work the lamp is increased in the same proportion.

The most economical effect is secured when the carbon strips are kept in a state of reasonably high incandescence. For example, if a small current is passed through a lamp the carbon may perhaps give a light equal to two candles, whereas by simply doubling the current the light may be increased ten times or more. The durability of incandescent lamps depends very much on the steadiness of the current with which they are supplied, but it may be assumed that a well-made lamp fairly treated will last 1,000 to 1,500 working hours.

CHAPTER IX.

Conductors. Arranging Lamps for Work.

The Conductors used for conveying the electric current from the generators to the lamp should be carefully proportioned to the work required of them.

When electricity passes along a conductor it meets with a certain amount of resistance, which varies with the size of the wire and the material of which it is made, and the conductor becomes more or less heated.

When the current of electricity is large and the diameter of the wire small, the resistance to the passage of the current is great, and the consequent heating effects are very marked. If the resistance is sufficiently great the wire will become white hot, and may even be melted.

Some metals offer less resistance to the passage of electricity than others, and are therefore called better conductors. The following table gives the relative conducting powers of a few of the metals; the conductivity of Silver being taken as equal to ... 100

that of Copper is	96
Gold	74
Platinum	17
Iron	16
Lead	8
German Silver	7·5
Mercury	1·6

The conductivity of metals is diminished by an increase of temperature.

The difference of resistance offered by various metals to the passage of electricity can be illustrated by a simple experiment. If a short piece of platinum wire is inserted between two lengths of silver wire of equal diameter, and a strong current of electricity is passed through them, the platinum wire will be heated to redness, whilst no alteration will be seen in the silver wire. This is because the platinum wire offers six times as much resistance to the passage of electricity as the silver wire does.

The resistance offered by conductors to the passage of the current requires a certain amount of power to overcome it, and all power so expended represents a cost for which there is no return in light, and which is, therefore, a certain waste which cannot altogether be avoided. The larger the area of the conductors the smaller will be the power required to force the electricity through them. But on the other hand the weight and cost of the conductors increase in proportion to their size, and a point is soon reached above which it is not economical to increase their bulk, as the interest on the extra first cost would more than counterbalance any annual saving that could be made in motive power.

Copper possesses very great conducting power, it is not easily oxidised, and is very pliable, and readily worked and jointed. It may therefore be considered the most suitable material for electric conductors for lighting purposes. Iron has only about one-sixth the conducting power of

copper, and therefore an iron wire would require six times the sectional area (and consequently about six times the weight) of a copper wire to offer only the same resistance. The cost of copper is more than six times that of iron, and therefore in the matter of first cost the iron wire would have the advantage. Iron is very inferior to copper in durability, and its extra weight and bulk (which is a disadvantage, especially when an insulating covering is required) render it only suitable for temporary purposes.

The exact diameter of conductor which will be most economical, depends on the nature of the current to be conveyed. To carry a given amount of electric energy without undue heating, the diameter of the conductor must be increased as the electromotive force of the current is decreased.

For example, the electric energy of a current is calculable by the formula $W = CE$.

Where W is work done.

C is current in amperes.

E is electromotive force in volts.

Thus, for a current with an E. M. F. of 50 volts and a strength of 10 amperes $W = 50 \times 10 = 500$.

As also for a current of 100 volts and 5 amperes

$W = 100 \times 5 = 500$.

For any given conductor the heating effect of the current

$H = C^2R$.

Where H is heat caused.

C is current in amperes.

R is resistance of conductor in ohms.

Therefore, for a conductor of say 1 ohm resistance, the heating effect of the current of 10 amperes and 50 volts E. M. F., would be $10 \times 10 = 100$, and that of the current of 5 amperes and 100 volts $5 \times 5 = 25$.

It is obvious from the above example that considerable economy may be effected in the cost of conductors by using currents of considerable E. M. F. Currents of high electromotive force however, are, to a certain extent, dangerous, and necessitate special precautions to prevent risk of accident.

In no case should a conductor be so small as to become perceptibly heated in working, because when metals become heated their resistance is increased, and the conducting power reduced. The resistance of copper increases about $\frac{1}{5}$ per cent. for each degree Fahrenheit increase in temperature. For small currents single wires are generally used, but for large currents conductors composed of several wires twisted together are to be preferred. A stranded conductor formed of several wires contains more weight of copper in *a given length* than the corresponding number of untwisted single wires of which it is formed, and has consequently a lower resistance.

Safe Working Current. The resistance of a wire varies inversely as the square of its diameter or as its sectional area, and therefore it would appear reasonable that when a current was increased in strength it would be sufficient to increase the area of the conductor in the same proportion. In other words, if a copper conductor of $\frac{1}{10}$ of a square inch area was large enough for a current of 50 amperes, two conductors of the same area, or a

single conductor of double the area (or $\frac{1}{20}$ of a square inch), should suffice for a current of 100 amperes.

The keeping cool of a wire, however, depends not only on its sectional area, but also on its radiating surface, and it is obvious a wire of $\frac{1}{20}$ of a square inch area has not double the radiating surface of a wire $\frac{1}{40}$ of an inch area, and as currents are increased in strength, it is prudent to increase the area of the conductor in a somewhat greater proportion.

Within certain limits, however, for wires of small diameter and cables composed of several wires twisted together, it is sufficiently exact for practical purposes to vary the area of the conductor in the same proportion as the current, and the size of wire required to convey any given current safely may be rapidly ascertained with sufficient exactness by the following formulæ :—

$$A = \frac{C}{1900} \text{ or } D = \frac{\sqrt{C}}{38}$$

Where C is safe current in amperes.

A is area of conductor in square inches.

D is diameter of conductor in inches.

The weight of copper in a mile of conductor may be roughly estimated by multiplying the safe current in amperes by 11, the result being in lbs. For example, a copper wire suitable for a current of 10 amperes would weigh $10 \times 11 = 110$ lbs. per mile.

Although wires of the sizes calculated by the above formula will carry the currents specified without risk of over-heating, it is not economical to use such small diameters except for very short leads, on account of the waste of power incurred in forcing the current through

the conductors, and as a general rule it is well to make the leads of such a size that their resistance shall not exceed more than 10 per cent. of that of the whole external circuit.

In practice, therefore, it is not so much a question how small a conductor may be used without over-heating, but rather what size of wire will be most economical, having regard, on the one hand, to the prime cost of the conductor, and on the other hand, to the annual cost of the motive power required to force the current through it.

The Insulation of electric light conductors is a point which needs careful attention. Except in those cases where all other considerations have to be sacrificed to low first cost conductors should be coated with an efficient insulating material. For indoor work, small wires may be covered with silk or cotton, with an under or over-coating of damp proof material.

Larger wires are generally coated with gutta percha or india-rubber ; the latter material, though slightly dearer, is to be preferred, as the former becomes soft when only slightly heated, and when subjected to the action of the weather is liable to lose its pliability and to crack. A very high class cable is produced by tinning the copper wires and coating them with soft rubber, over which a coating of vulcanised rubber is added, the cable being finished by winding in opposite directions with two coverings of india-rubber cloth or tarred tape. Whenever conductors are exposed to damp, a sound waterproof insulating covering is absolutely essential. All wires

conveying currents of high electromotive force must be well insulated to avoid risk of accident by contact.

Special cables are now obtainable made with an outer coating of lead pipe, and may be used with advantage in special circumstances.

For ordinary work not exposed to the weather, the insulated wires may be run in grooved timber, which can be obtained direct from the saw-mill at small cost. When wires have to be placed in walls where they are liable to be injured by nails being driven into them, they may be protected by running them in small iron tubes.

For underground work, conductors can be placed in metal or earthenware pipes, or troughs, with connecting boxes at suitable distances to permit of easy examination. For work of this class the insulation is rendered more certain by filling up the channels containing the cables with pitch, or similar waterproof insulating material.

For overhead work, copper conductors have not sufficient tensile strength to be safe for long spans, and in such cases iron wires should be used from which the copper conducting cables may be suspended.

The jointing of electric conductors requires to be very carefully done. Wires and cables should be spliced or twisted together, the ends being scraped clean to ensure good contact, and a coating of solder being added to complete the joint. Conductors may also be joined by metal sleeves with set screws to hold the wires in position tightly, or by brass binding screws and nuts.

When the insulation of a conductor has been removed

to make a joint, care should be taken that after the soundness of the connection has been ascertained the insulation should be again effected by coating with an efficient covering of insulating material.

Terminals, or binding screws, are used to connect the conducting wires to the generators and lamps. Precautions should be taken to conceal or protect all connections sufficiently to prevent any chance of the current being short-circuited by accidental or mischievous connecting of the terminals where they are so placed as to be readily accessible.

Position of Wires.—It is desirable to be able to ascertain at a glance which are positive or leading wires (usually termed "leads"), and which are negative or "return" wires.

Leading wires running vertically may be placed to the Left or in the Lower position if running horizontally, and Return Wires may be placed to the Right, or in the Raised position when horizontal.

Where it is necessary to leave the ends of the wires loose for a time, they may be labelled L and R. The position of the wires is easily remembered, as

L stands for Leads, Left, or Lower position.

R stands for Returns, Right, or Raised position.

Switches or Commutators must be provided wherever it may be necessary to shut off the current or to change its direction. The working parts must be proportioned to the currents for which they are intended, and should be so constructed as to ensure proper contact when the current is passing, and to be sufficiently apart

when the circuit is open to render it impossible for an arc to form at the point where the contact is broken. The portions of the switches which break contact should not have sharp edges, which promote sparking, but should be rounded off where practicable. For strong currents it is advisable to use switches so designed as to break the circuit simultaneously at two or more points.

Safety plugs or bridges are formed by introducing into the circuit short lengths of easily fusible wire, or of metal foil. A composition made of 60 parts of lead to 40 parts of tin is suitable for this purpose.

A wire of the above composition, No. 25 B. W. G. (Birmingham wire gauge), or ·02 of an inch diameter, will carry safely a current of two amperes. A wire No. 21 B. W. G. (·032 inch) will carry four amperes; for larger currents the sectional area of the wire must be increased in more rapid proportion, a wire No. 16 B. W. G. (·065 inch) being required for a current of 10 amperes, and No. 12 B. W. G. (·109) for 25 amperes. If by any accident the current through the conductor is materially increased, the fusible wires are melted, and the danger of the conductor being over-heated is obviated.

Safety bridges should be introduced at each point where wires are branched off from the main conductors, and should be placed where they can be easily got at and replaced when necessary. For incandescent lights, where the greatest risk of an accidental short circuit is at the lamps, the fusible bridge may be conveniently introduced in

a small box containing a switch, by which the lamp can be turned on or off as desired.

The **Edison safety cut out** consists of a block, Fig.

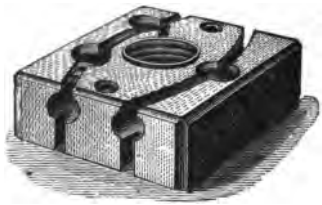


Fig. 50.

50, to which the conducting wires are attached, and a central screw plug, Fig. 51, containing a short piece of wire formed of lead and tin, through which the current passes to the lamps, and which is fused if the current exceeds the limit of safety.

The fusible portion of the **Hedges patent cut-out**

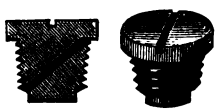


Fig. 51.

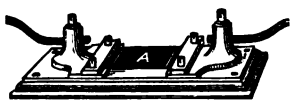


Fig. 52.

(see Fig. 52) is composed of strips of metallic foil, A, supported by thin sheets of talc, and can be easily replaced if melted.

The diameter of wires is usually defined by what is called the Birmingham wire gauge; the following table gives the relative diameters expressed in B. W. G. and in inches.

No. B. W. G.	Inches.	No. B. W. G.	Inches.	No. B. W. G.	Inches.
0	·340	9	·148	17	·058
1	·300	10	·134	18	·049
2	·284	11	·120	19	·042
3	·259	12	·109	20	·035
4	·238	13	·095	21	·032
5	·220	14	·083	22	·028
6	·203	15	·072	23	·025
7	·180	16	·065	24	·022
8	·165				

The resistance of *pure* copper wire *per mile* may be calculated by the formula

$$R = \frac{\cdot 054892}{D^2}$$

where R is Resistance per mile in ohms.

D is Diameter of wire in inches.

To prevent risk of fire, it is desirable that dynamos should be placed so as not to be exposed to chance of contact with any easily combustible material. The circuit from and to the machine should be wire or cable throughout, gas pipes and earth completing circuits being avoided. Switches should be fixed on stone or other incombustible material. Main lead and return wires should be as far separated as practicable, and where currents of high electromotive force are used, should be secured some inches apart. When conductors are formed of strands of several wires *kinks* must be carefully avoided, or a portion of the wires may be broken, and serious heating result.

The resistance of the external circuit, of which

the lamps form part, must, in any system of electric lighting, bear a certain proportion to the internal resistance of the dynamo itself. Generally, for shunt wound machines, the external resistance is arranged to be fifteen to twenty times that of the armature, but the exact proportion depends on the relative resistance of the armature and of the shunt circuit for the electro-magnets. If the external resistance is too great, sufficient current will not be sent through the lamps; but if on the other hand it is too small, the electro-magnets will not be sufficiently excited, because the resistance of the shunt circuit will be too great in proportion to that of the main circuit, and consequently it will not receive its proper share of current. In the ordinary series dynamo, if by any chance the external conductors are accidentally joined (or short-circuited, as it is called), as would be the case if the terminals of the machine were connected by a stout wire, the armature coils will be heated to such an extent as to destroy the insulating material with which the wire is covered, and the machine will be rendered useless. Care must be taken in arranging the lamp circuit, that the resistance may be suitable to the dynamo employed to supply the current.

Arc Lights are either used *singly*, one in each circuit, or are coupled up one after the other *in series*, the current passing from the dynamo to the first lamp, and then through all the other lamps in order, and back to the machine.

The resistance of a single arc lamp is generally from one to three ohms, but varies with the strength of the

current; when several are coupled in series the resistance of the circuit increases in a slightly more rapid proportion than the number of the lamps.

When a number of arc lamps are arranged in series, the resistance of the circuit is correspondingly great, and it needs a dynamo giving a current of high electromotive force to work it. For example, if there are twenty lamps in circuit, giving a total resistance in machine, conductors, and lamps, of 60 ohms, and requiring a current of 10 amperes, the electromotive force required would be 600 volts, and may be calculated by the formula

$$C = \frac{E}{R} \text{ or } E = RC$$

Where C is the current in amperes.

R is the resistance in ohms.

E is the electromotive force in volts.

It is not always practicable to regulate the speed of the dynamo to exactly suit the number of lamps that may be in circuit at any given time, and it is convenient to have a series of resistance coils that may be included in the circuit as required. These coils may be simply constructed of spirals of German silver or of iron wire. The ordinary coiled door springs will answer the purpose, and at small cost. The ends of the coils may be connected to a circular switch or commutator, having as many contact plates round its circumference as there are coils. In this way the resistance of the external circuit may be readily increased or diminished as required. Any useless resistance in the external circuit necessitates a waste of power, and with shunt wound machines the electromotive force can be more economically adjusted to suit the

number of lamps by arranging the resistance coils and commutator to form part of the shunt circuit round the magnets; the strength of the magnetic field, and consequently the E. M. F. of the machine, being reduced in proportion as the resistance of the shunt circuit is increased.

Incandescent Lamps can be connected up to the dynamo in several ways.

I.—*In series* (see Fig. 53), the current passing by the conductor AB through all the lamps in succession. In this case the total resistance is *equal to the resistance of all the lamps added together.* For example, if there were four lamps, each of 40 ohms resistance, the total resistance, when connected in series as above, would be 160 ohms.

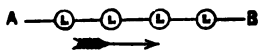


Fig. 53.

II.—The lamps may be connected in *parallel circuit*, or *multiple arc*, as it is more commonly termed (see Fig. 54)

In this case A and B represent the main conductors from and to the machine, the lamps being fixed, as it were, in little bridges of wire connecting the two main conductors together.

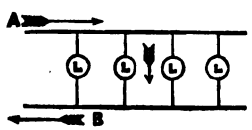


Fig. 54.

Assuming, as before, each lamp to have a resistance of 40 ohms, the resistance to the current of the four lamps would be only 10 ohms, or one-fourth of the resistance offered by a single lamp.

That is to say, when lamps of equal resistance are connected up in parallel circuit, the total resistance is

equal to that of one lamp divided by the number of lamps.

In other words, the resistance of the circuit is decreased in proportion as more lamps are added in multiple arc, as the current has more paths open to it by which it can pass from one main conductor to the other.

III.—The lamps may be connected up in any combination of the above two methods (see Fig. 55). In this case the resistance of each of the two connecting branches taken separately, would be that of two lamps of 40 ohms in series, *i.e.*, 80 ohms, but as there are two paths for the current to cross instead of one, the total resistance between the conductors would be only half 80 ohms, *i.e.*, 40 ohms. That is to say, the total resistance is *equal to that of one branch divided by the number of branches.*

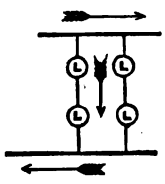


Fig. 55.

The resistance of a system of lamps, and the electromotive force required to overcome this resistance, can be varied as shown above; but although the electromotive force can be in this way reduced, the lamps always require a certain amount of current, and the total energy or *work needed to supply the four lamps would be exactly the same in each of the three examples*, Figs. 53, 54, and 55.

The electrical energy or work required for any purpose can be calculated by multiplying the current in amperes by the electromotive force in volts ($W = CE$).

In the above examples each lamp has been supposed to have a resistance of 40 ohms, and if it is assumed that it also requires a current of one ampere, the electromotive

force will be as follows, because the electromotive force is equal to the resistance multiplied by the current ($E=RC$).

In Fig. 53, $R=160$, $C=1$, and therefore $E=160$, and $W=CE=(1\times160)=160$.

In Fig. 54, $R=10$, $C=4$, and therefore $E=40$, and $W=(4\times40)=160$.

In Fig. 55, $R=40$, $C=2$, and therefore $E=80$, and $W=(2\times80)=160$.

The electrical work can be expressed in horse-power by dividing 160 by 746 (by formula $HP=\frac{CE}{746}$), and therefore in each of the above examples the power required to work the four lamps would be $\frac{160}{746}$ HP, or rather less than a quarter of a horse-power.

Semi-incandescent Lamps and **Electric Candles** may either be worked with a separate circuit for each light, or coupled up in series.

It will be seen from the above examples that, although when many arc lights are required at distances which make it almost essential to couple them up in one circuit, currents of high electromotive power cannot be avoided, yet that with incandescent lamps, there is no such difficulty, since by arranging them in parallel series the resistance of the external circuit may be reduced to any extent that is desired, and consequently that currents of very small electromotive force are sufficient. The practical importance of this as regards the safety of using the electric light is very great. If by any accident a person should touch the conductors of a machine of small electromotive force, supplying a circuit of low

resistance, he would only draw off a very small portion of the current and suffer no inconvenience, because the resistance of the human body is very great (more than 1,000 ohms) and that of the circuit very small, and electricity always divides itself in exact proportion to the facility of passage offered to it.

Although a person may touch two conductors having a difference of potential of 100 to 200 volts, and sustain no harm, yet if the same experiment were repeated with an electromotive force much exceeding the above strength, a very serious shock, if not actual death, might result.

When handling electric light conductors through which a current may be passing, it is obviously safer to use one hand only where practicable. Care should also be taken not to stand on damp earth, or metal plates or beams, or on anything that would form a good conducting medium from the conductor to the earth through the body. India-rubber gloves and shoes may be used as a matter of precaution when working with currents of high electro-motive force.

CHAPTER X.

Compound Circuits. Electrical Testing.

When a conductor is divided into two or more branches, the circuit is said to be a **compound circuit**, and the electric current divides itself among the branches in proportion to the facility of passage which each offers. If, as in Fig. 56, the main circuit is divided into two branches having respectively a resistance of a and b, the conductivity of each branch, being the reciprocal of its resistance, will be represented by $\frac{1}{a}$ and $\frac{1}{b}$, and the **joint conductivity** by $\frac{a+b}{a\,b}$. The amount of current that will flow through each branch will be inversely proportional to its resistance. For example, if the resistance of $a = 1$ ohm, and of $b = 2$ ohms, two-thirds of the current will flow through a and one-third through b.

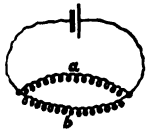


Fig. 56.

The **joint resistance** of the two branches is the reciprocal of their joint conductivity, and is equal to *the product of the separate resistances divided by their sum*, or in the above example to $\frac{a\,b}{a+b} = \frac{2}{3}$ ohm.

A similar rule holds good when a conductor is divided

into more than two branches, as in Fig. 57, where there are three branches of the relative resistances a, b, and c. The conductivity of the branches will be respectively $\frac{1}{a}$, $\frac{1}{b}$, and $\frac{1}{c}$, and their joint conductivity $\frac{1}{a} + \frac{1}{b} + \frac{1}{c} = \frac{ab+ac+bc}{abc}$ The joint resistance being $= \frac{abc}{ab+ac+bc}$ If, in the above example, $a = 1$ ohm, $b = 2$ ohms, $c = 3$ ohms, the total resistance will be $\frac{6}{2+3+6} = \frac{6}{11}$ of an ohm.

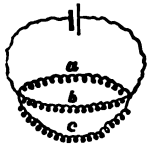


Fig. 57.

Electrical testing. It is frequently necessary in electric lighting installations to ascertain the resistance of a conducting cable or wire. This can be done without difficulty by means of a battery, a series of coils of known resistance, and a galvanometer.

Resistance coils for testing purposes are usually formed of German silver wire, as the resistance of this metal is comparatively little affected by changes of temperature. The wire is always wound double (see Fig. 58) so as to prevent induction, and the coils are usually fixed in a box, and their ends attached to brass blocks a slight distance apart, but which can be connected together by the insertion between them of turned brass plugs. When the plug is taken out the current can only pass from one brass block

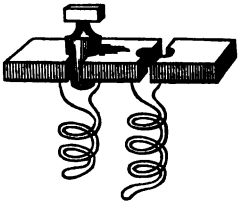


Fig. 58.

to another through the resistance coil attached to them, but when the plug is inserted the resistance between the blocks is so small that it may be neglected. The coils are usually arranged in an increasing series thus, 1, 2, 2, 5, 10, 20, 20, 50, up to 10,000; in this way any number of ohms from 1 to 20,000 can be put into circuit by a suitable arrangement of the plugs.

Fig. 59 represents a battery, B, galvanometer, G, and a wire, R, the resistance of which it is desired to ascertain.

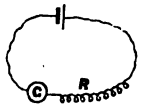


Fig. 59.

On completing the circuit the galvanometer needle will take a certain deflection, which must be noted. The wire R must then be removed from the circuit, and coils of known resistance introduced into its place, and varied until the needle of the galvanometer deflects to the same angle as with the original wire, the resistance of which is thus ascertained to be equal to that of the known resistance.

A more convenient method is to couple up the unknown resistance R, and the known resistance r, in such a way that they may be alternately thrown into circuit by the moveable key K (see Fig. 60), the known resistance being varied until the desired adjustment is arrived at.

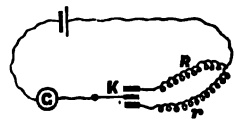


Fig. 60.

In comparing resistances, as above, it is not essential that the deflection of the needle shall be identical both with the known and unknown resistance, provided the

relative values of the degrees of deflection of the galvanometer are known. In some cases the index of the instrument is so divided into degrees of unequal size as to represent a uniform increase of current for each division of the index. More commonly, a galvanometer is used in which the tangent of the angle of deflection is proportional to the strength of current; such an instrument is termed a **tangent galvanometer.** This instrument generally consists of a circular coil of thick copper wire, about 12 inches diameter, at the centre of which is suspended a short magnetised steel needle surrounded by an index. In using this instrument, if an unknown current C gives a deflection of m degrees, and a known current c a deflection of n degrees, then,

$$C : c :: \tan m : \tan n$$

or $$c = C \frac{\tan n}{\tan m}.$$

The differential galvanometer is an instrument in which a magnetised needle is suspended between two coils of wire, wound side by side. If two equal currents are sent through the coils in opposite directions, they will neutralise each other, and the needle will not move. The resistance of any conductor can be ascertained by arranging it in circuit with one of the coils, and adding known resistances to the circuit of the other coil until no deflection is caused by a battery current sent through both coils in opposite directions. The resistance of the conductor will then be equal to the sum of the resistances in circuit with the other coil.

The Mirror Galvanometer must be employed for investigations where great sensitiveness is essential. In

this instrument the needle is suspended by a fine silk fibre, and has attached to it a small mirror. A beam of light is thrown on to the mirror from an adjacent lamp, and is reflected on to a fixed graduated scale, so that a very small movement of the needle causes a magnified movement of the spot of light on the scale.

In using very sensitive galvanometers it is better not to pass the whole of the current through the instrument until the resistances have been adjusted and practically balanced, but in the first place to allow part of the current to pass through a shunt circuit introduced between the terminals of the galvanometer.

The Wheatstone Bridge is a convenient combination of resistances for testing purposes. The principle of the arrangement is shown in Fig. 61, where a battery circuit is divided into two branches, *a c b* and *a d b*. A galvanometer is placed in a branch connecting the points *c* and *d*. In order that there may be no movement of the galvanometer needle, it is necessary that the potential of the points *c* and *d* should be equal, and this can only be when the resistance A : R :: B : *r* and A : B :: R : *r*. If the resistances A, B and *r* are known, R can be calculated for $R = \frac{r A}{B}$.

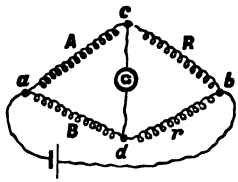


Fig. 61.

The branches A and B contain coils of known resistance, which can be arranged so that A may be either equal to B or to 10, or 100 times B. The branch *r* comprises a series of resistance coils, usually ranging from 1 to 10,000

ohms. The conductor, the resistance of which it is desired to test, is coupled up so as to form the branch R. The various resistances are then adjusted until the galvanometer needle remains at rest, when the value of R can be calculated by the above formula. The three sets of resistance coils A, B and r, are usually contained in one box. It is essential that there be some resistance in the branches A and B, otherwise the galvanometer is short-circuited, and will give no deflection, no matter what the resistances in the other two branches may be. It is well, not only to have a key to break the battery circuit, but also one to break the branch circuit in which the galvanometer is placed. In using the instrument the battery circuit should always be completed first.

In electric light installations, two kinds of tests have to be made, viz., tests of resistance and tests of insulation.

I. **Tests of Resistance.**—Conducting cables and wires used for the electric light are usually specified to have a conductivity equal to 96 per cent. of that of pure copper.

The resistance of a conductor can be rapidly tested by the Wheatstone bridge method, or any of the other plans which have been described. As the working of the lamps depends a good deal on the conducting wires being properly fitted up, it is desirable that when the main conductors and branch wires are in position, they should be carefully tested.

To effect this, the connecting wires should be detached from the lamps, and the ends of the main cable be joined, and its resistance ascertained by one of the plans described above. Afterwards, the main *lead* should

be connected up to one terminal of the branch B (if the Wheatstone bridge is used), and the main *return* to the other. The branch wires should then be connected one after the other at each lamp, and the resistance of each circuit examined. In order that all the lamps may give an equal light, it is essential that the resistance of the leading wires should be as nearly as practicable the same.

II. **Tests of Insulation.**—To test the insulation of a conductor, a battery giving an electromotive force equal to that of the working dynamo current should be used; a series of chloride of silver cells are very convenient for this purpose. One end of the cable to be tested is coupled up to the galvanometer, the other end being perfectly insulated. One pole of the battery must be connected to earth, and the other to the second terminal of the galvanometer, a suitable key for making contact being included in the circuit. When contact is made, the deflection (d) of the galvanometer needle must be noted. A similar method may be followed when all the branch wires have been connected to the cables, care being taken that before commencing the test all lamp connections are broken, and the ends of the wire left perfectly free from contact with anything.

To obtain the value of the insulation resistance in ohms equivalent to the observed deflection (d) of the galvanometer needle, the cable must be disconnected from the instrument, which is then joined up in simple circuit with the battery and a resistance coil (r) of high resistance. The deflection of the needle (d^1) having been noted, the

insulation resistance of the cable will be to that of the known resistance coil inversely as the tangent of the first deflection to that of the second. For example, if the first deflection (d) is 2 degrees, and the second (d′) 45°, and the resistance of the known resistance coil (r) 10,000 ohms, the insulation resistance will be as follows:—

$$\left.\begin{matrix}\text{Insulation}\\ \text{Resistance}\end{matrix}\right\} = 10{,}000\ \frac{\tan 45^\circ}{\tan 2^\circ} = 286{,}368 \text{ ohms.}$$

In the above calculation the resistance of the galvanometer is neglected, as it is assumed to be only a minute fraction of that of the resistance coil. Frequently, however, it is necessary to take into consideration not only the resistance of the galvanometer, but also that of the battery, in which case the formula

$$R = \frac{\tan d'}{\tan d}\, r \text{ becomes } R = \frac{\tan d'}{\tan d}\,(r + b + g) - (b + g).$$

Where R is the unknown resistance to be determined,

r ,, known resistance,

d ,, angle of deflection with unknown resistance,

d′ ,, angle of deflection with known resistance,

b ,, resistance of battery,

g ,, ,, ,, galvanometer.

When the resistance of the battery is small enough to be neglected the formula becomes

$$R = \frac{\tan d'}{\tan d}\,(r + g) - g.$$

CHAPTER XI.

Storage of Electricity.

One of the chief difficulties in the way of a general house-to-house supply of the electric light is the want of a simple and economical system of storage. So long as the electric current is supplied direct from the generator to the lamps, there must be a risk of occasional failure of the supply, which may be caused by the breakage of a driving belt, or any similar temporary derangement to which even the best designed and most carefully worked machinery is liable.

A system of storage is absolutely essential to the working of the present gas supply, and would be almost equally valuable to any extended system of electric lighting.

Without storage it is almost necessary to duplicate the generating machine, or at any rate to provide a considerable percentage of spare power to lessen the inconvenience of any temporary breakdown. Whilst, on the other hand, a practical system of accumulating electricity would admit the use of less powerful and costly machinery, which could be used during the day time, and the power thus stored up would be available to meet the varying demand of the evening and night.

Electricity can be stored on a small scale, suitable for experimental purposes only, in an apparatus called a

Leyden jar, which is constructed as follows:—A glass jar is coated to a certain height inside and outside with tinfoil, and the two coatings are charged, the one with positive and the other with negative electricity. The mutual attraction between the two charged coatings enables them to retain a far greater amount of electricity than could be imparted to two isolated pieces of tinfoil of similar size.

Sheets of tinfoil separated by parafined paper are sometimes used instead of a Leyden jar when larger capacity is desired; such an arrangement is called **a condenser.**

The quantity of electricity that can be stored by means of the above apparatus is limited, and it is quite impracticable to adapt this method of accumulation to practical electric lighting.

No other plan is at present known of storing electricity directly as such, but by acting on certain substances by an electric current in such a way as to decompose them, electricity may be transformed into chemical energy, which in turn can be re-transformed into electrical energy.

The ordinary galvanic battery contains a store of chemical energy ready at any moment to appear in the form of an electric current, and may be considered practically a store of electricity which can be drawn upon until the active materials are exhausted. In order to replenish this store, the products of the chemical action must be removed and fresh material supplied, which is equivalent to reconstructing the battery. It has been found that the replenishing may also be effected by passing a current of electricity through the battery in a direction

opposite to that of the current originally produced. Although any galvanic battery may be thus used as a storage battery, it is preferable to select materials which, when acted upon by a current, will offer a very small resistance, and produce a cell capable of yielding a high electromotive force, and consequently a corresponding strength of current.

Such an arrangement is termed **a secondary or storage battery**, or, less correctly, an **electrical accumulator.**

When a current is passed through two platinum plates immersed in acidulated water, the liquid is decomposed, hydrogen being given off at one plate and oxygen at the other. If the main current is stopped, and the plates are connected with a wire, a current in the reverse direction will flow between them.

Grove's gas battery is an example of the electromotive force producible by the contact of gases with metal plates in a battery. Each cell consists of two platinum plates immersed in a vessel of acidulated water, the upper portion of one plate being surrounded by a tube containing oxygen, and the other plate by a similar tube containing hydrogen. The two plates are connected by a wire passing up through the upper ends of the tubes. When the circuit is thus completed the current flows, and chemical combination takes place between the two gases through the medium of the acidulated water.

If two plates of lead are used, one of them being in a bright metallic condition and the other in a peroxidised condition—that is to say, presenting a surface of peroxide

of lead—it will be found, on connecting them by a conductor, that a current will flow along it from the peroxidised plate to the other, the bright plate becoming gradually oxidised, and the peroxidised surface of the other becoming gradually reduced to a less oxidised condition.

If two strips of plain clean lead are used, and a current is passed through them by connecting them with three cells (in series) of a Daniell or other battery, peroxide of lead will be seen to form on the plate connected with the positive pole of the battery. When the plates are disconnected from the battery and joined by a wire, a current will flow through it from the peroxidised plate to the other as above described.

The above experiment is an example of a storage battery in its simplest form, and all so-called electric accumulators, or secondary batteries, are based on the same principle.

The various oxides of lead have the following chemical composition:—

The protoxide of lead, usually called **litharge**, is of a yellow colour, and consists of one atom of oxygen to one of lead. (PbO.)

The oxide next in order is commonly called **red lead**, or **minium**, and consists of four atoms of oxygen to three of lead. (Pb_3O_4.)

The **peroxide**, or **brown oxide of lead**, contains two atoms of oxygen to one of lead. (PbO_2.)

Of the three oxides the peroxide alone is a *conductor* of electricity.

Plante's Secondary Battery, brought out in 1860, consisted of two sheets of lead rolled up into a cylinder, and kept from contact with each other by strips of insulating material fixed between them. The plates were placed in a vessel containing dilute sulphuric acid, and connected one to each pole of an electric generator. The current passing through them caused the oxidation of one plate, and set free hydrogen at the other. The plates were then detached from the generator, and connected by a conductor, and allowed to discharge themselves; the effect being that the oxide of lead was reduced on the one plate, and the other became oxidised. A second current was next sent through the plates from the generator, but in the reverse direction, and the process repeated again and again till the surface of the plates became spongy, and a thoroughly formed cell was produced. This system of preparing the cells occupied a very long time, and at a more recent date, modifications have been made in secondary batteries, by which the process of formation of the plates is much expedited, and at the same time their storage capacity is materially increased.

In the **Faure Battery** the lead plates are coated with a thick layer of red lead or minium, which is retained in position by a casing of felt. The current is only passed through the cells in one direction, and when the charging is completed, it is found that the red-lead is reduced on one plate to metallic lead in a spongy condition, and on the other plate it is converted into lead peroxide. The process of forming cells on this plan is many times more rapid than the original Planté plan. A reverse action takes place

when the cells are discharged through a conductor until both plates are brought to the same condition.

Plans have been brought forward to facilitate the adhesion of the minium, and increase the effective area of the plates by perforating or corrugating them, or by cutting grooves in their sides.

In the **Sellon-Volckmar Batteries** the lead plates are cast with numerous small square holes in them, which are filled with red lead. The batteries are formed by a current of uniform direction, and have large storage capacity; the plates are placed in rectangular cells of glass or ebonite, and are separated from each other by strips of india-rubber.

The plates of the **Watt Battery** are formed by subjecting molten lead to the action of a jet of steam. In this way finely divided particles of lead are projected against a flat surface, and adhere to each other, forming a coherent sheet of porous lead of any desired thickness, and presenting a large area to the action of the charging current, thereby facilitating the formation of the plates.

The Kabath accumulator is constructed with a combination of flat and corrugated lead plates, and that of **De Meritens** with lead plates folded so as to form narrow troughs, which are filled up with lead foil.

Sutton's Battery is formed of one plate of lead amalgamated with mercury, and the other of copper, in a cell containing a slightly acidulated solution of sulphate of copper.

In charging secondary batteries, a current of one ampere passing through a cell for 110 hours can convert a pound

weight of litharge into peroxide of lead on the one plate, and at the same time reduce another pound into metallic lead on the other plate. To convert a pound of metallic lead into peroxide requires a current of one ampere to pass for 230 hours. To change a pound of minium to peroxide needs a current of one ampere for 70 hours.

When litharge or minium are immersed in the acid solution, a certain amount of sulphate of lead ($Pb.SO_4$) is formed; this, however, is again decomposed by the passage of the current. Peroxide of lead is not converted into sulphate by the acid.

A secondary battery, when fully charged, has an electromotive force of from two to two and a third volts. The resistance of a cell depends on the size of the plates, and the distance they are apart. It is desirable that the plates should be placed as close together as practicable that the resistance may be reduced as far as possible, and in order that they may store much energy the plates should have a large working surface.

In charging cells the current from the dynamo has at first only to overcome the resistance of the cells, which is usually very small, but almost immediately each cell sets up an opposing electromotive force (which may amount to nearly two and a half volts), and the charging machine must develop an E.M.F. rather greater than that of all the cells in series in order to drive the current through them. The cells may be charged more rapidly if arranged in two parallel rows; in this way both the resistance of the cells and the opposing electromotive force are diminished by half. It is not economical to use too strong a current for

charging accumulators, or gas is given off in the cells, and power consequently wasted.

The number of cells *in series* must not exceed two-fifths of the maximum electromotive force of the machine in volts, but several rows of cells may be arranged parallel, and charged at the same time. For cells of ordinary size, a charging current of one ampere may be advantageously used for each 100 square inches of acting plate surface (*i.e.*, reckoning both sides of each set of plates, positive and negative). The acid solution used in the cells is composed of seven parts of water to one of ordinary sulphuric acid. In charging accumulators the positive pole of the dynamo must be connected to the positive pole of the cells. The ordinary *shunt wound* dynamo is the most suitable machine for the purpose. The *compound shunt wound* and *series* machines are less suitable, because if from any reason the speed of the dynamo is reduced, and its electromotive force diminished, the batteries will overcome the current from the dynamo, and begin to discharge themselves through the armature. The direction of the current round the magnet coils being in this way reversed, the polarity is changed, and the armature may suffer injury from the intense current produced by the machine and batteries combined. If machines of this class are used, it is essential that an automatic cut-out be inserted between the dynamo and the batteries, in order that the circuit may be broken instantly any reversal of current takes place. With a shunt dynamo, however, there is no risk of this kind, as even if the current is accidentally reversed, the current round the magnet shunt circuit remains in the same direction, and consequently no reversal of polarity is possible.

When secondary batteries are used at the same time as a dynamo for supplying the current to a number of incandescent lamps, they must be placed so as to form a shunt circuit, or, in other words, must be arranged as a branch between the main conductors just in the same way as each lamp is. The number of batteries in series must give the same electromotive force as the lamps require.

When the batteries are used without the dynamo it is better to have a rather greater E.M.F. than required by the lamps, and to regulate the strength of the current by a variable resistance in the main circuit to the lamps, rather than to vary the number of batteries. It is very desirable that each battery of the series should be kept as far as practicable in the same condition, and this is impossible if some are worked for longer periods than others, unless very special precautions are taken. The external variable resistance should, however, not be larger than absolutely necessary, as it, of course, entails a certain waste of power.

The purposes to which accumulators can be applied are very numerous. When used in combination with a dynamo they facilitate the production of an even steady light in the lamps. They also enable the dynamo to be run during the daytime when the lights are not required, the electricity thus stored being available for the supply of an extra number of lights in the evening.

Accumulators may be used to furnish motive power for tramcars, carriages, or tricycles on land, and for boats on the water. They form a convenient source of power for driving sewing machines, or other light machinery.

The number of hours an incandescent lamp will last depends very much on the steadiness of the current with which it is supplied, and secondary batteries afford a simple means of equalising the current.

When electricity has to be transmitted to long distances, it is economical to use currents of high electromotive force, and which are consequently to a certain extent dangerous. The accumulator provides a means of reducing these powerful currents to an intensity which is perfectly harmless.

The chief obstacle to the employment of secondary batteries is their comparatively high cost, some notes on which will be found on a subsequent page.

CHAPTER XII.

Selection of Light. Cost of Electric Light.

The type of electric lamp most suitable for any given purpose must be decided on the particular circumstances of the case. Where a uniform illumination of moderate power is desired, the incandescent lamps offer marked advantages, but where a more powerful light is necessary the comparative cheapness of the arc light tells in its favour.

For the illumination of **large open spaces** out of doors, the arc lamps are undoubtedly the most suitable and economical. They may either be of large power, and fixed singly or in groups at a considerable height above the ground; or of smaller power and more in number, and fixed at a less elevation. The former plan may be adopted for large public squares where a mast of suitable height for carrying a large lamp (or group of lamps) can be erected in a central position. But for smaller spaces, especially where a central lamp standard would be objectionable, better lighting is effected by arranging a few smaller arc lamps at suitable intervals a short distance from the outside edges of the area to be illuminated.

For **large covered spaces**, such as Railway Stations and Markets, similar considerations apply. Where the roofs

consist of large open spans, say over 100 feet, and of considerable height, lamps of great power may be used with advantage, suspended high up and at some distance apart.

In cases where the roofs are of smaller span and less height, lamps of smaller power, at a height of about 15 feet above the floor level, will afford more perfect illumination.

As a rough guide to the number of lamps required for the purposes above described, a nominal candle power of 1,000 candles may be assumed for every 1,000 to 2,000 square feet of floor surface to be illuminated, according to the degree of light desired.

For ordinary **street lighting** three systems of lamps may be adopted, without taking into consideration the plan that has been tried in America of erecting light towers of great height (200 feet or more), with lamps of enormous power, capable of producing a daylight (or moonlight) effect over a large area.

I.—Arc lamps of 500 to 1,000 candle power, placed, say 200 to 300 feet apart.

II.—Semi-incandescent lamps, or electric candles of 200 to 400 candle power, placed about 100 to 150 feet apart.

III.—Incandescent lamps, say two lamps of 16 candle power, or one lamp of 30 candle power, which may be very well arranged for use in the lamp posts at present used for gas, and which are generally placed at intervals not exceeding 70 or 80 feet.

For **general interior illumination**, arc lamps of high

power are unsuitable, what is required being a well distributed light of moderate intensity, the particular class of light most suitable depending very much on the special circumstances of each case.

For **large public buildings**, which have been lighted by the arrangement of gas burners usually called a sunlight, fixed in the ceiling, arc lights up to 1,000 candle power may be used, but care should be taken to, as far as possible, distribute the lights; for example, two lamps, each of 250 candle power, arranged at a suitable distance apart, will give a better effect than a single lamp of 500 candle power. There are several reasons for this; in the first place, the light will be more uniform in a given space if distributed from two points instead of one; secondly, shadows will be more easily avoided; and thirdly, less annoyance will be caused by the variations in the light caused by the unavoidable inequalities in the quality of the carbons used in these lamps.

For **large shops**, small arc lights or semi-incandescent lamps will produce good effects, and a pleasant degree of illumination can be obtained from the often abused electric candle. Lights of this class have been in constant use for several years, in many large establishments, with satisfactory results.

For **workshops** and **manufacturing establishments**, the most suitable arrangement of lights can only be arrived at by a careful examination of the nature of the operations carried on. As a general rule, large works can be most efficiently and economically lighted by a combination of arc and incandescent lamps. The arc lamps being used

to illuimnate the large spaces sufficiently to allow of the general operations being carried on safely, and the incandescent lamps being grouped and distributed so as to afford the light required at each machine, or by each workman.

For ordinary **domestic illumination**, the incandescent lamps are unequalled; and for quality of light, safety, and convenience of management, leave little to be desired. Lamps of 16 to 20 candle power are most suitable, and can be readily adapted for use on existing gas chandeliers and brackets, the carrier of the lamp being arranged to screw on in place of the ordinary gas burner. The lamps can be used either with or without containing globes, and a pleasing effect can be produced by means of coloured glass globes or shades. Reflectors of opal glass diffuse the light advantageously. Incandescent lamps readily lend themselves to artistic arrangement, and since they do not tarnish, they can be combined with brass or other metal scroll work in a way that has been impossible with gas. For rooms of moderate size and height, two lamps of 20 candle power each will give a sufficient light for each 100 square feet of floor surface. For lofty rooms, and for those with dark papers and furniture, the number of lamps must be correspondingly increased. A better effect is produced when the lights are carried on wall brackets than when they are suspended from central chandeliers.

For **Steamships**, the incandescent lamps are most generally useful, though arc lights of small power can, with advantage, be used in the engine-rooms. The greater comfort and safety of electric light, as compared with the

old system of oil lamps, must lead to its rapid adoption in all large passenger steamships.

For out-door lighting, it is essential that the arc lamps should be provided with suitable **protecting lanterns**, fitted with reflectors to cast down the light and aid its distribution. For indoor illumination, it is always necessary when arc lamps are used to provide containing globes to diffuse the light, and prevent danger of fire from falling pieces of incandescent carbon. A certain loss of light is unavoidable by the use of these globes, which should be made as little opaque as possible. The proportion of light rendered non-effective by the globes may be roughly estimated as follows :—

Plain glass about	10 per cent.
Frosted glass about	25 ,,
Opal or coloured glass about ..	50 ,,

The cost of the Electric Light depends to a great extent on the special conditions of each installation, in the same way as the price of gas varies in different localities from 6s. to 2s. per 1000 cubic feet, according to the area supplied, and the local facilities for manufacture.

No exact rules can be given for calculating the cost of electric lighting *generally*, but when the conditions of any proposed installation are known, a sufficiently exact estimate can be formed.

The chief items of expenditure are :—

I.—The **interest on capital** spent on apparatus, **depreciation** of plant, and **repairs.**

II.—The cost of **motive power** and **attendance**; **rental of premises**, &c.

III.—The **maintenance** or **renewal** of lamps.

In comparing the cost of electric light with that of gas, it is generally stated that under ordinary conditions electric light on the arc system is cheaper than gas, and on the incandescent system more expensive. Much, however, depends on the number of hours the light is used annually, for whilst the cost *per hour* of a gas light remains constant whatever time it is kept burning, on the other hand the cost *per hour* of the electric light rapidly decreases as the number of hours it is used is increased. This is obvious when it is considered that the interest on capital, rental of premises, and other similar charges remain the same whether the electric lighting plant is used one hour or twelve hours, and that consequently the expense *per hour* will be materially reduced in proportion as the number of working hours are increased.

As it is convenient to have some standard of comparison in contrasting one means of illumination with another, a light equal to **1,000 standard candles** burning for the period of **one hour**, may be taken for the purpose.

The quantity of **Gas** required to produce the above light (assuming the standard burner using five feet per hour to give an illumination equal to 16 standard candles) would be 312 cubic feet, which at 2s. 9d. per thousand cubic feet would cost 10½d. For electric light the calculation is more complicated.

With **Arc Lights** it may be assumed that the expenditure of one indicated horse-power is necessary to maintain a light equal to 1000 candles. One indicated horse-power may be obtained by the consumption of 4 or 5 lbs. of coal per hour, costing less than ¼d., or, if a gas engine is used, of 22 cubic feet of gas, costing ¾d. The cost of carbons

for an arc lamp of the above power will be about 1¼d. per hour. For installations of from 5 to 6 arc lamps of this size, the dynamo, lamps, conducting wires, engine and boiler (or gas engine), may be estimated at £65 per indicated horse-power (or per lamp), including cost of foundations, counter-shaft, pulleys, fixing, etc. An allowance of 10 per cent. for depreciation, repairs, and interest on capital expended, gives a cost of £6 10s. 0d. per annum, or 1½d. per hour if the lamps are used four hours per day, or say 1,200 hours per year. Adding ¼d. per hour for oil and sundries, and 2d. for the proportion of attendants' time necessary for each lamp, the total cost would stand as follows:—

Fuel	¼d.
Carbons	1½d.
Repairs and Interest	1½d.
Oil and sundries	¼d.
Proportion of Attendance ...	2d.
Total per arc light of 1,000 candles	5½d. per hour.

For larger installations it is possible to materially reduce the above costs, and the expense of arc lighting may be taken generally to vary between 3d. to 6d. per 1,000 candles per hour, according to the number of lamps, and the time during which they are used annually. For a less number of lamps than five, the cost, however, would be proportionately increased.

At the **South Kensington Museum**, the following is stated to be the result of nine months' working of the electric light.

The Lord President's Court was formerly lighted by gas,

at a cost of 16s. per hour (4,800 cubic feet at 3s. 4d. per 1,000 cubic feet), or £560 per annum. The cost of working the sixteen Brush lamps by which the gas was replaced, including cost of carbons, fuel and wages, amounted to 3s. 10d. per hour, or £134 per annum. The capital outlay for engine, dynamo, and lamps, was about £1,000; and allowing 10 per cent. for depreciation and repairs, the total cost of the electric light per annum would be £234 as against £560 for gas.

For **Incandescent Lamps**, the cost is proportionately higher than for arc lamps, as one indicated horse-power will only afford about 150 to 200 candle-power (instead of 1,000 as with the arc lamps), and, consequently, to produce 1,000 candle-power, 50 lamps of 20 candles each must be used, and an engine capable of transmitting to the dynamo an effective five horse-power, the fuel for which would cost 1½d. per hour. The cost of dynamo, wires, lamps, engine, boiler, and fixing, may be taken at £350; the charge for interest and depreciation and repairs at 10 per cent. would be £35, or 7d. per hour for 1,200 hours per annum. As the lamps can only be calculated upon to last 1,000 hours, an allowance must be made for renewals, which at 3s. each would amount to 1½d. per hour for the fifty lamps. Adding 2½d. for oil, sundries, and attendance, the total cost would be :—

Fuel	1½d.
Repairs and Interest	7d.
Renewal of Lamps	1½d.
Sundries and Attendance ...	2½d.

Total of cost of 1,000 candle power 12½d. per hour.

A larger number of lamps would be comparatively less costly, and a smaller number more expensive.

If a gas engine is used instead of a steam engine, it may be assumed that 22 cubic feet of gas, costing ¾d., are required to produce one indicated horse-power, and that, therefore, the extra cost of fuel would be ½d. per indicated horse-power per hour.

The cost of semi-incandescent lamps and electric candles may be assumed to be between that of arc lights and of incandescent lights.

Summarising the above figures, the approximate relative cost of producing a light equal to **1,000 standard candles**, would be as follows :—

Gas (at 2s. 9d. per 1,000 cub. feet)	10½d.	per hour.
Arc lamps (5 to 10)	5½d.	,,
Do. in large installations ...	4d.	,,
Incandescent lamps	12½d.	,,
Do. if worked by gas engine	15½d.	,,
Semi-incandescent lamps or electric candles	8d. to 10d.	,,

In the above calculations, the absolute cost of production of the light alone is considered, and no allowance is made for expenses that would necessarily be incurred in establishing centres for distributing electricity on a similar system to that of the present gas supply. The preceding figures give some idea of the cost at which the electric light can be produced by manufacturers or others for their own use, and it should be remarked that in cases where motive power is available without additional capital expenditure, the above costs may be materially reduced.

Although the cost of producing a given amount of light by incandescent lamps is considerably greater than that of arc lamps of equal power, yet great practical advantages are secured by the greater facility for distribution of the light.

Sixteen candles distributed in a room will give a much more even and useful illumination than one gas burner of the same nominal power, and in the same way the light of 50 incandescent lamps, each of 20 candle-power, is for most purposes more efficient than a single arc light of 1,000 candle power. It is somewhat doubtful whether with lights of very high candle power the *useful* effect is nearly as great as the *nominal* illuminating power would seem to indicate.

The use of incandescent lamps is very rapidly extending, and when employed on a large scale their cost is very little, if any, in excess of gas of equal illuminating value.

Mr. Conrad W. Cooke, in a report to the **Corporation of Sheffield** on the cost of lighting certain districts of that town with 10,000 incandescent lamps, arrived at the conclusion that, assuming one horse-power to be required for every 8 lamps of 20 candle-power, the capital expenses would be as follows.

	£	s.	d.	
Electrical apparatus	1	1	2	per lamp
Motive power	1	2	4	„
Distributing plant	0	17	9	„
Land and buildings	1	0	0	„
Contingencies, Engineering, etc.	0	8	2	„
Total capital per lamp ...	£4	9	5	

Assuming that the lamps would be used on an average 3,000 hours per annum, the cost of each lamp was estimated thus :—

	s.	d.
Production of current	5	6½
Maintenance (repairs)	5	9
Management	1	0
Interest on Capital (5 per cent.)	4	6
Total cost per annum for 3,000 working hours	16	9½ per lamp

In the above estimate no allowance is made for the renewal of lamps (which would probably amount to 7s. 6d. for 3,000 hours), nor for cost of rendering and collecting accounts, and other office expenses which would probably cost at least 2s. 6d. per lamp. If these allowances are added, the cost per lamp per annum would be about 27s.

A 5-foot gas burner of equal illuminating power would require for 3,000 working hours 15,000 cubic feet of gas, which at 2s. 9d. per 1,000 would cost 41s. or about 50 per cent. more than the incandescent lamp.

The above result, apparently so favourable to the electric light, is due to the fact that this calculation is based on 3,000 working hours per annum, and a very low price for coal (7s. per ton). If the working hours per annum are estimated at 1,500, which is possibly as high an average as would be likely to be found in practice, the cost of the gas light would be reduced to 20s. 6d. per annum, whilst the cost of the electric light would probably not be reduced

below 20s. Any further decrease in the number of working hours would render the comparison less favourable, and it is obvious that on smaller installations the cost of the electric light per lamp would be materially higher than the above figures, which are based on a very large installation of 10,000 lamps, under circumstances which may be regarded as specially favourable.

Mr. Octavius E. Coope has published some interesting particulars with respect to the relative cost of lighting a country house by electricity as compared with private gas works.

Careful estimates were obtained for each system of lighting, and it was found that for 200 lights (of 20 candle-power each) the capital expenditure required for gas plant, including all chandeliers and fittings, and cost of fixing, was £1,334 (or £6 13s. 5d. per light); and for electric plant, fixed complete, £1,470 (or £7 7s. 0d. per light). The cost of working per annum Mr. Coope estimated to be for gas £400 (or £2 per light), and for electric light £233 or £1 3s. 4d. per light).

Where water power is available within reasonable distance, the cost of the electric light can be materially reduced, and also in cases where spare engine power is available and has not to be specially provided.

The cost of electric-lighting plant is enhanced, for the reason that the machinery must be of sufficient size to drive the maximum number of lights that may be required at any given time, and cannot be proportioned to suit the average number of lights.

If a cheap and practical system of storing electric energy

could be devised, considerable advantage would result; but the present price of **storage batteries** is almost as great as that of the machine power they could replace (viz., about £4 for each incandescent lamp supplied), and in addition a certain per centage of power is lost in charging the batteries.

The use of accumulators has many practical advantages, especially with regard to steadiness of current, and immunity from extinguishing of the light during any temporary break-down of machinery. In cases where lights are required at long distances from the generating station, considerable economy is effected by the use of currents of high electromotive force, and accumulators afford a simple means of reducing these high tension currents to a safe limit. There is reason to think that accumulators of improved design and reduced cost will play an important part in the future in any general system of house to house lighting.

Galvanic Batteries are seldom used for electric lighting on a practical scale, the cost of producing any given amount of electricity by means of batteries being about 20 times the cost of production when a steam engine and dynamo are used for the purpose.

CHAPTER XIII.

Motive Power. Steam Engines. Gas Engines. Water Power.

The successful working of an installation of electric lighting machinery depends to a very large extent on the motive power provided. Any want of steadiness, which in the motor itself may be scarcely noticeable, is multiplied by the high speed of the generating machinery into a serious variation in the lighting. This renders it for the most part necessary that the motor employed for this purpose should not, at the same time, be used for any other work which is subject to variation.

The three most available sources of power are—

I.—**The Steam Engine.**

II.—**The Gas Engine.**

III.—**Waterwheels, or turbines.**

The special circumstances of each installation must influence the selection of the most suitable motive power.

The Steam Engine, in the majority of cases, is the most economical motor. A well-constructed engine, if provided with a sensitive governor, will maintain a very uniform speed, and when used for a varying number of lights, will regulate the consumption of steam, and consequently of fuel, to suit the amount of work required.

Condensing Engines effect a saving in fuel, but this advantage is practically counterbalanced by their greater first cost, and consequent extra charges for interest and depreciation.

High Pressure Engines, fitted with automatic expansion gear, give very satisfactory results.

Rotatory Engines have the great advantage of dispensing with any intermediate gearing, and occupy but small space; they are, for the most part, however, wasteful of steam, and from their high speed liable to require somewhat frequent repairs and renewals of working parts.

Portable Engines should be of the two cylinder type, as they run more steadily than single cylinder engines. The newly-introduced **compound-portable engines**, with high and low pressure cylinders, run very steadily, and are very suitable for electric lighting. **Semi-portable Engines**, with the cylinders under the boiler, require no foundations, and are largely used for this purpose. The size of engine necessary, of course, depends on the number of lamps required, but it may be assumed that each indicated horse-power will furnish the electrical energy required to supply one arc lamp of 1,000 candle effective power, or 8 incandescent lamps of 20 candle-power each. The indicated horse-power of an engine can be calculated by the formula

$$HP = \frac{P.D^2 R.S}{252{,}000}$$

Where P is average steam pressure in cylinder in lbs.

D ,, dia. of piston in inches.

S ,, length of stroke in inches.

R ,, number of revolutions per minute.

The Boiler used for generating the steam has an important bearing on the cost of working a steam engine. Where space is no object, the ordinary double-flued **Lancashire boilers**, fitted with Galloway's tubes, are simple and efficient, and very inexpensive as regards repairs. In cases where the space at disposal is limited, cylindrical **multitubular boilers**, or semi-portable boilers of the locomotive type, may conveniently be used.

The Gas Engine offers considerable advantages where only a small number of lights are required, and in such cases is more economical than a steam engine. It takes up but small space, can be started at a moment's notice, and does not need any skilled attendance. The action of gas engines is not so regular as that of a steam engine, and to prevent the constant slight variation in speed from being unpleasantly reproduced in the lamps, it is necessary that the dynamo should be fitted with a fly-wheel, and that a counter-shaft should be provided between the gas engine and the dynamo. It may also be necessary in cases where the number of lights is subject to variation to steady the motion of the gas engine by an extra fly-wheel fixed on the crank shaft, or on the intermediate shaft.

Waterwheels, or Turbines, are very suitable motors for electric lighting machinery, as they require but little attention, and under proper conditions maintain a very uniform speed.

A natural water supply, within reasonable distance of the place where the light is required, offers very considerable economical advantages. The wheel, or turbine, need not necessarily be close to the building to be lighted, but

the dynamo may be fixed near the stream, and the current be conveyed by wires to the place where the lamps are required.

The size and prime cost of turbines for any given power increases rapidly as the height of the supply, or head of water available decreases. It is, therefore, advisable to take advantage of any increase of pressure that can be obtained by running pipes from the place where the machinery must be fixed to points up and down the stream, between which the greatest difference of level can be obtained within reasonable distance. Iron pipes must be used for water under high pressure, but for low pressure wooden troughs or earthenware pipes are less costly conductors.

Turbines may be arranged to work by the pressure of the whole available head of water, in which case they are fixed at the lowest position possible, or, to derive their power partly from the pressure of water above them, and partly from the suction of the escaping water below, in which case they are placed in an intermediate position. The following formula gives approximately the actual horse-power that can be obtained by means of a turbine, from any given water supply.

$$H\,P = \frac{QH}{13}$$

Where Q is quantity of water in cubic feet per second.

H ,, head of water in feet.

It is not often possible or convenient to drive the dynamo by direct connection with the prime motor, and without the intervention of intermediate shafting and pulleys.

All **Shafting** used for this purpose should be of ample

size and strength to work without vibration, and the bearings should be long, and rigid enough to secure steady working.

Pulleys running at high speeds must be accurately balanced, and should be slightly rounded on the face, to ensure the true running of the belts. Fast and loose pulleys for stopping the machinery are better arranged on a counter-shaft than on the axis of the dynamo itself.

The **belting** used for driving electric lighting apparatus cannot be too carefully selected. The joints should be "butt" *not* "lap" joints. It is desirable to have a considerable margin in strength, and single belts should not be subjected to a working strain of more than 30lbs. per inch of width. The width of belt required may be calculated thus—

$$B = \frac{1350\ HP}{S} \quad \text{or} \quad \frac{5000\ HP}{DR}$$

Where B is width of single belt in inches.

HP „ actual horse-power to be transmitted.

S „ speed of belt in feet per minute.

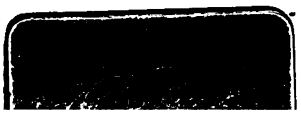
D „ diameter of pulley in inches.

R „ number of revolutions per minute.

Lubricators should be fixed on all bearings, and care should be taken to ascertain that they contain a proper supply of oil before the machinery is started. The bearings of dynamos, or of other shafts which revolve at high speed, should be examined occasionally when at work, so as to detect, and, as far as possible, prevent any undue heating.

The foundations on which electric lighting plant is fixed, demand special attention, as the high velocity at which the machinery works causes excessive vibration,

unless everything is firmly bolted down. Timber beams of suitable size make a satisfactory base for dynamos to stand on, and also for the bearings carrying the requisite counter-shafts. As a general rule, it is well for the machinery and shafting, as far as possible, to have concrete or stone foundations in the ground, and not to attach brackets and bearings to the walls of the building. Vibration and noise may in this way be reduced to a minimum.

A speed indicator is a useful adjunct to motors used for electric lighting machinery, the good working of the light depending to such a great extent on the maintenance of uniform speed.

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